ИЗВЕСТИЯ
АКАДЕМИИ НАУК СССР
СЕРИЯ ГЕОЛОГИЧЕСКАЯ

IZVESTIYA AKAD. NAUK SSSR

SERIYA GEOLOGICHESKAYA

1961 CONTENTS No. 1, January

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CHRONICLE

TWENTY-SIXTH YEAR OF PUBLICATION

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ON THE THRESHOLD OF A NEW QUARTER CENTURY (OUR JOURNAL IS TWENTY-FIVE YEARS OLD)[1]

Izvestiya of the Academy of Sciences, U. S. S. R., Geologic Series, was first published in 1936. It was the first specialized issue of the formerly general Izvestiya of the Academy of Sciences, Division of Mathematical and Natural Sciences, and the first geologic journal in the Academy system.

The creation of a geologic journal in the year 1936 was due to the extraordinary success in this country in fulfilling the first five-year plans of the state economy. In order to satisfy the ever-growing industrial needs for raw material, it became necessary to increase the mineral resource base, and consequently to broaden and deepen the study of the immense expanse of our state in the process of building socialism. It was quite natural that a greater need arose in this connection for geologic information, experience exchange, formulation of current geologic problems, and their discussion in geologic publications.

Beginning with the very first issue, edited by Academicians I. M. Gubkin, A. D. Arkhangel'skiy, and V. A. Obruchev, this publication was directed by our most outstanding scientists. Thus, in addition to these three men, the following participated in the work on this magazine, either as Chief Editors or members of the Editorial Board: Academicians A. Ye. Fersman, A. N. Zavaritskiy, D. S. Belyankin, P. I. Stepanov, also S. S. Smirnov and the late N. S. Shatskiy, talented representatives of a more recent period of Soviet development of geologic science.

We particularly note here the active and continual participation in our editorial work, of the dean of Russian geology, Hero of Socialist Labor, Academician Vladimir Afanas'yevich Obruchev. From the beginning of this journal and to the end of his days, he directed Izvestiya, first as editor then as a member of the Editorial Board; he also was the author of many articles and communications in the "Criticism and Discussion".

The issue of No. 12 of Izvestiya, 1960, marked twenty-five years of this publication. There have been 175 issues published in that period, with about 2400 titles reflecting more or less completely the trends, problems, and features of development of geologic science in the Soviet Union, not purely academic but affecting the geologic organizations of this country as a whole. This magazine has never been confined to narrow departmental interests. Its pages have been wide open for all exploration organizations: for a number of years, about half of the papers published were written by non-academic geologists.

Major research papers on the most urgent and momentous problems, the treasure of Soviet geologic literature, have reached a wide circle of readers through the geologic series of Izvestiya, long the only magazine in all fields of geology.

Thus, as early as 1937 and 1938, Academician V. I. Vernadskiy published here his papers "On the Boundaries of the Biosphere" and "Some Main Problems in Biogeochemistry"; F. Yu. Levinson-Lessing, "The Problem of Magma" (1939) and "Extrusive Rocks" (1940); A. Ye. Fersman, "Achievements in the Study of Pegmatites from Granite Magma" (1939, No. 2) and "Geochemistry of Cobalt" (1939, No. 3); A. D. Arkhangel'skiy, "Gravimetric Studies in Central Asia and Southwestern Kazakhstan" (1936, in cooperation with V. V. Fedynskiy), "Geologic Significance of Gravity Anomalies in the U. S. S. R. " (1937, in cooperation with V. V. Fedynskiy et al), "Some Controversial Points in Tectonic Terminology and Tectonics" (1939).

Shortly before his death in 1939, Academician I. M. Gubkin wrote in this magazine on the importance of geology in fulfilling the Five-Year Plan of the U. S. S. R. state economy.

During the Great Patriotic War, under the conditions of evacuation and isolation from many objects of geologic work, our magazine, although

[1]Na poroge novoy chetverti veka. (Nashemu zhurnalu dvadtsat' pyat' let).

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unable to reflect the diversified interests of the army of Soviet geologists dispersed over the land, did not interrupt its publication, appearing for a few times only in joint issues. P. S. Stepanov's paper on the value of the coal resources of the U. S. S. R. for defense (No. 1) was published in 1942.

The following post-war papers by leading scientists, published here, are noteworthy: V. A. Obruchev, "Main Features of Kinetics and Plastics in Neotectonics" (No. 5, 1948); A. N. Zavaritskiy: 1) "Main Problems of Physical Chemistry in the Formation of Pegmatites" (No. 5, 1944); 2) "Some Features of Volcanism in Armenia" (No. 1, 1945); 3) "Observations on Geologic Terminology" (No. 1, 1947); 4) "Ignimbrites of Armenia" (No. 3, 1947); D. S. Belyankin: 1) "Petrography and Petrology" (No. 2, 1944); 2) "Some General Problems in Modern Petrography" (No. 6, 1944); 3) "The Status and Prospects of the Theory of Magmas and Igneous Rocks" (No. 5, 1947); S. S. Smirnov: 1) "Tin-Tungsten Mineralization in Eastern U. S. S. R." (No. 6, 1945); 2) "The Pacific Ore Belt" (No. 2, 1946); 3) "Some General Problems in the Study of Ore Deposits" (No. 5, 1946); Yu. A. Bilibin: 1) "General Principles of Metallogenic Study" (No. 5, 1947); 2) "Problems of Metallogenic Evolution in Geosynclinal Zones" (No. 4, 1948); A. G. Betekhtin: papers on manganese (No. 4, 1944), mineragraphy (No. 6, 1945), and mineral paragenesis (No. 2, 1949); A. P. Vinogradov: 1) "Geochemistry of Isotopes" (No. 3, 1954); 2) "Meteorites and the Earth's Crust" (No. 10, 1959); D. I. Shcherbakov, on exploration maps for igneous ore deposits (No. 4, 1952); K. I. Satpayev, on exploration metallogenic maps of Central Kazakhstan (No. 6, 1953); D. S. Korzhinskiy, on the mobility of components (No. 1, 1936; No. 2, 1949); on metasomatism (No. 3, 1950; No. 6, 1951; No. 4, 1953); A. A. Polkanov: 1) "Heterogeneity of Foyalites" (No. 5, 1944); 2) "Genetic Systematics of Platform Intrusions" (No. 6, 1946); 3) "Principles of Geologic Mapping and the Problems in Petrology of Intrusive Bodies" (No. 5, 1947).

Along with this list of titles on petrography and mineralization, purely geologic subjects have been given their proper place in the pages of this magazine.

The foremost among these are a series of papers by N. S. Shatskiy on the comparative tectonics of ancient platforms (No. 1, 1946; No. 6, 1946; No. 5, 1947; No. 5, 1948) as well as his other works: 1) "The Duration and Phases of Folding" (No. 1, 1951); 2) "Paragenesis and Formation of Sedimentary and Volcanic Rocks" (No. 5, 1960). Also important are N. M. Strakhov's works: 1) "Types of Sedimentation in Geologic History" (No. 2, 1946); 2) "The True Significance of Bacteria in the Formation of Carbonate Rocks" (No. 3, 1947); 2) "Periodicity and the Irreversible Nature of the Evolution of Sedimentation in the History of the Earth" (No. 6, 1949; also D. V. Nalivkin's 1) "Variscian Folding in the Urals" (Nos. 4-5, 1941); 2) "Supratenuous Structures and Paleogeography in the Paleozoic of Second Baku" (No. 2, 1943); 3) "Middle Carboniferous in the Southern part of the Ufa Amphitheater" (No. 2, 1949); 4) "Bauxites in the Urals" (No. 4, 1942).

Of unquestionable interest are papers by a number of leading Soviet geologists of a younger generation. Such are G. D. Afanas'yev's works on intrusives and igneous activity in the Caucasus (No. 4, 1949; No. 4, 1952; Nos. 1 and 5, 1953; No. 4, 1955; Nos. 2 and 11, 1957); V. V. Belousov's on the movement and structure of the earth's crust (No. 5, 1948; No. 2, 1955); on tectonic investigations (No. 4, 1958); A. V. Peyve's on deep faults (No. 5, 1945; Nos. 1 and 3, 1956); on the inheritance principle in tectonics (No. 6, 1956; Ye. V. Pavlovskiy's 1) "Comparative Tectonics of Mesozoic-Cenozoic Structures in East Siberia and the Great Rift of Africa and Arabia" (No. 5, 1948); 2) "Certain General Regularities in the Development of the Earth's Crust" (No. 5, 1953); 3) "Zones of Pericratonic Subsidences" (No. 12, 1959); M. V. Muratova's on the structural elements of the crust (No. 1, 1946; No. 5, 1948); V. I. Smirnov' on metallogenic regional differentiation (No. 4, 1949); K. A. Vlasov's on the origin and genetic types of rare-metal granite pegmatites (No. 1, 1956; No. 12, 1957).

Our readers know that this magazine has covered fairly completely the discussion of sedimentary rocks (No. 4, 1950; Nos. 2-3, 1953), of regularity in the development of igneous activity (Nos. 1 and 4, 1953), and of a number of other problems specifically dealt with at All-Union and interdepartmental conferences, such as the discussion on tectonics (No. 5, 1948), on the book by Kh. M. Abdullayev "Genetic Relationship of Mineralization and Intrusions" (No. 4, 1951; No. 3, 1955), and many others, too numerous to mention.

This selective list of titles, far from complete, shows the broad and comprehensive scope of this magazine. However, it was not until the recent specialization of the scientific press that it became possible for the Editorial Board to take up a number of current problems previously neglected for lack of space.

The initiation of a number of geologic magazines in the provinces has freed this magazine from the task of printing many papers of purely local interest; at the same time, such new journals as "Geology of Ore Deposits", "Geochemistry", and the "Paleontologic Journal", have unloaded our portfolio of narrowly specialized papers. The present selection of material for Izvestiya is in a broader scientific field — regional geology. This has resulted in the publication of a number of papers on the geology

of foreign countries, such as G. D. Afanas'yev's on igneous activity in Egypt (No. 3, 1960); Ye. V. Pavlovskiy's on Precambrian and Lower Paleozoic tectonics of Scotland (Nos. 6-7, 1958); on the tectonics of France and South Germany (Nos. 9 and 11, 1960); V. V. Belousov's on the tectonics of Central and South China (No. 8, 1956); and V. M. Sinitsyn's on the tectonics of Central Asia (Nos. 1 and 6, 1948).

Personal contacts established in recent years between Soviet and foreign geologists, as well as the participation of our scientists in the work of international organizations, particularly the International Geological Congress, have found their reflection in this magazine (D. I. Shcherbakov, "The Twentieth Session of the International Geological Congress in Mexico City", No. 12, 1956; "The Ninth Session of the Pacific Congress in Bangkok", No. 8, 1958; D. S. Korzhinskiy, "The Indian Scientific Congress in Baroda", No. 4, 1956; "The Annual Meetings of the Geological Society of America", No. 4, 1959, and many others).

In recent years, this magazine has published the works of foreign authors, as well; e. g., on igneous activity and the distribution of ore deposits in Bulgaria, by the late Bulgarian Academician Str. Dimitrov (No. 3, 1959); on illite, by the Czechoslovakian mineralogist J. Konta (No. 11, 1960); and on paleomycology by K. Beneš (No. 11, 1960); on taxonomy of spores by the German stratigrapher R. Potonier (No. 6, 1959); etc.

By means of a reciprocal agreement with the Société Géologique de France, in 1960, this magazine published a Russian translation of papers by the French geologists F. Mangain, on orogeny of the Pyrenees (No. 6, 1960) and P. Routier on metallogenic studies in France (No. 10, 1960).

In the past year, this magazine gave expression to geologic thought on many problems of general scientific interest, such as the structure of the crust (G. D. Afanas'yev, No. 7, 1960) and paleomagnetism (P. N. Kropotkin, No. 12, 1960).

In the early nineteen fifties, following the conference on the age determination of geologic formations by radioactive methods, organized by the Section of Geologic-Geographic Sciences, Academy of Sciences, U. S. S. R. (see No. 5, 1952), this magazine began to publish papers on radiogeochronology. Since then, this subject has been given a prominent place in these pages as it has come to occupy in the work of Soviet geologists; published in No. 10, 1960 was the "Geochronologic Scale of Absolute Dating", a systematic classification of the results of studies of many years in various laboratories of the Soviet Union. Of much interest in this respect is the paper by B. M. Keller, G. A Kazakov, I. N. Krylov, S. V. Nuzhnov, and M. A. Semikhotov (No. 12, 1960) on Rhiphean stratigraphy as worked out on the basis of a joint application of geochronologic and purely geologic methods.

In concluding this selective and incomplete description of the contents of Izvestiya of the Academy of Sciences U. S. S. R., Geologic Series, mention should be made of the momentous initiative of this magazine in assisting in preparation and publication of G. L. Pospelov's paper, "Geology as a Science and its Place Among Natural Sciences", which is an attempt at a philosophical interpretation of the scientific achievement of twentieth century geology. It is to be hoped that this paper will stimulate an exchange of opinions leading to a deeper and more complete understanding of problems facing the several branches of geology in this new stage of development of our knowledge.

This striving of our Editorial Board for a comprehensive representation of the major and urgent problems in geology and of its achievements has not always been successful: the publication of papers has been slow; it has taken about a year from the arrival of material to its publication. This, of course, is quite unsatisfactory.

The future goal of this magazine should be a shortening of the publication time, perhaps through a stricter selection of manuscripts, in order to lighten the editorial portfolio and to facilitate editorial work.

It also must be admitted that the Criticism and Discussion section is not as good as it should be. There still is too much incidental material and not enough organized selection of the publications reviewed.

The Editorial Board believes that its task in the future should be an analysis of problems pertaining to geology and the state economy.

It will not be long before geologists will work out a scientifically substantiated theory of the structure of the earth's crust and the upper mantle. In this field, as in the field of the state economy, geologists should look for assistance from a new branch of geology, radio- or isotope-geology.

Geologists must discover the true laws of the origin and distribution for commercial minerals, such as oil and gas, and such as iron, manganese, nickel, copper, lead, rare elements, and non-metallic minerals.

In the next few decades, the need for all sorts of mineral raw material will grow immeasurably, in connection with the further growth of our industry. Unavoidably there will arise problems of total and comprehensive

utilization of raw material, not regarded now as ores; perhaps, for example, serpentines carrying nickel, chromium, cobalt, and magnesium, or extrusive rocks carrying rare elements.

All this, based on the development of modern methods and supported by advances in physics, chemistry, and progressive technology of production and beneficiation of commercial minerals, undoubtedly will generate a new flow of scientific ideas and practical recommendations.

The time is near when geologists will have to get ready for studies in their field on other planets, as well.

The present progress of science is so rapid as to make it difficult to make any predictions, even for the next ten years. In any event, this magâzine should be ready to deal with new problems and with the results of their solution by the collective creativity of Soviet geologists.

PRINCIPLES OF CLASSIFYING GRANITE PEGMATITES, AND THEIR TEXTURAL-PARAGENETIC TYPES[1]

by

K. A. Vlasov

For over 15 years, this author has returned, on many occasions, to the problem of a textural-paragenetic classification of rare-metal granite pegmatites. This subject was best covered in Izvestiya of the Academy of Sciences, S. S. S. R., ser. geol., No. 2, 1952.

In recent years, the author has observed and studied many additional pegmatite fields in the Soviet Union and abroad — in China, Morocco, India, Spain, and the United States. An analysis of field data, coupled with information on this subject by the personnel of the Institute of Mineralogy, Geochemistry, and Crystallography of Rare Elements, as well as by the personnel of other Soviet organizations, and added to a study of foreign literature on pegmatites [8, 9], fully corroborates the truth of the principles of our textural-paragenetic classification of granite pegmatites.

We know now the importance of structure, texture, and mineral paragenesis in a classification of granite pegmatites, in their origin, spatial distribution relative to mother intrusions, in determining the regularities of the distribution in them of rock-forming and rare-metal minerals, and consequently the geochemistry of their component elements. At the same time, we have become aware of shortcomings in earlier variants of the textural-paragenetic classification, and of the new problems calling for solution.

One of the most important problems is the role of pegmatites with large accumulations of albite and spodumene, in a textural-paragenetic classification. In earlier variants, these pegmatites were included in the fourth rare-metal-replacement type, as its youngest member and consequently as the youngest product of the pegmatite process in general ([4], Figure 2, top).

Recent discoveries of new spodumene-bearing pegmatite fields of this type in the Soviet Union, United States, Canada, Africa, and other countries, as well as their intensive commercial development, suggest the necessity of isolating these albite- and spodumene-rich pegmatites as an individual type V. Since the name, albite-spodumene pegmatite, has been well established in scientific literature, we shall retain it, inasmuch as it reflects, in a general way, the specific features of its paragenesis.

Of great importance in understanding the origin and classification of pegmatites is whether their albite-spodumene varieties are developed as a branch of the pegmatite process or are merely a more or less independent link in the chain of over-all evolution of pegmatite bodies. Evidence on hand is in favor of the second alternative.

The following facts point to albite-spodumene pegmatites as a continuation of preceding types of the textural-paragenetic classification: 1) the classic fields of albite-spodumene pegmatites always contain veins of other pegmatite types; 2) those fields where pegmatites of types I-IV are developed, but not type V, show a gradual increase in features of the latter, from type to type, such as the increase in albite and spodumene, up to commercial amounts; an intensification of replacement processes; etc.

With albite-spodumene pegmatites grouped as an individual type, the textural-paragenetic classification acquires a more finished aspect; at the same time, the role of this industrially important pegmatite group in our classification is determined. For completeness and unity of exposition, a brief description of other types in the textural-paragenetic classification is given below, along with that for type V, with some corrections necessitated by new data. For comparison, two variants are presented in Figure 1, where (a) is the preceding and (b) is the new one.

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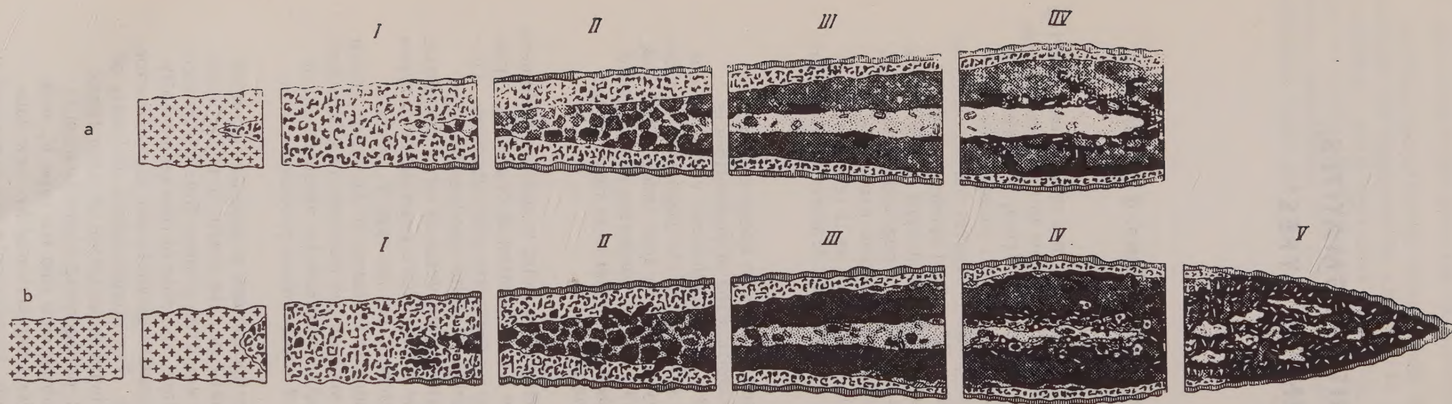
[1]Printsipy klassifikatsii granitnykh pegmatitov i ikh teksturno-parageneticheskiye tipy.



The following items increase from mother granite to more advanced pegmatite types: the degree of differentiation in pegmatite, the size of individual mineral grains (including type IV); the content of highly volatile compounds; the amount of albite and quartz; the content of rare elements and the amount and variety of rare-metal minerals (including type IV); the role of the hydrothermal stage in replacement processes, and the volume of replacement minerals.

The following items decrease: the comparative amount of pegmatite with a granitic and graphic texture; the content of microcline and orthoclase.

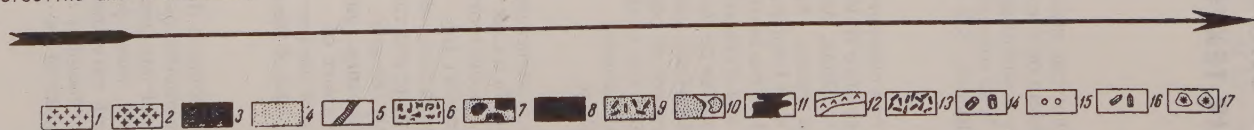


FIGURE 1. Diagram of textural-paragenetic pegmatite types.

a) preceding; b) new variant.

1 - granite; 2 - pegmatoid granite; 3 - microcline; 4 - quartz; 5 - contact fringes and zones of a muscovite-quartz-feldspar composition; 6 - graphic and granitic pegmatites; 7 - block zone; 8 - monomineral microcline zone; 9 - quartz-spodumene zone; 10 - blocks and zones of quartz; 11 - replacement zones and complexes: albite,[1] quartz, muscovite, microcline relicts, rare-metal minerals: lepidolite, beryl (commonly containing cesium), niobate-tantalates, polychrome tourmaline, spodumene, etc.; 12 - lepidolite zone; 13 - spodumene; 14 - beryl; 15 - pollucite; 16 - amblygonite; 17 - in cavities: minerals of kaolinite group, quartz crystals, lepidolite, kunzite, etc.; I-IV) textural-paragenetic types.

[1]Because of identification difficulties, the replacement complex combines albite of two generations: formed in the process of replacement and formed independently from pegmatite melts.

PRINCIPLES OF PEGMATITE CLASSIFICATION

It is well known that the task of working out a scientific classification for natural bodies, within a class or a family — be they animal, vegetable, or mineral — is as difficult as it is important. This difficulty arises from the fact that bodies grouped in the same class are in fact stages of a single evolutionary process, with all shades of commonly imperceptible transition between them. Because of that, designation of types within a class or a family; e. g., a rock family, calls first of all for determining well-defined boundaries marking a sharp change in properties, as a result of which the bodies acquire essentially new features in the process of evolution. Identification of such criteria reflecting the basic features of natural bodies and setting one type apart from the other is the principal task in working out any classification. It should be kept in mind that in the progress from one link to another, (from type to type), the change affects a complex of criteria, including the secondary, rather than a single principal criterion. For this reason, the value of a classification depends on how typical its criteria are, and how accessible to observation. To be sure, classification criteria may change in time, with new methods of study, as witness crystallochemical structures which, along with chemical composition, have recently become one of the main classification criteria for minerals.

As of now, there are several classifications of pegmatites, based on various principles. Some students, both here and abroad, classify pegmatites by their mineral composition, into microclinic, microcline-albitic, albitic, albite-microclinic, and muscovitic; others classify them by chemical composition, into lithium, sodium-tantalum, beryllium, and other pegmatites. There are high- and low-temperature pegmatites; also simple and compound, according to their chemical and mineral composition; etc.

A detailed critical analysis of various pegmatite classifications [10, 15, 16] has been made before by the author [4]. We believe that they have the common fallacy of being, as a rule, one-sided and qualitative, without a quantitative evaluation of either the chemical or mineral aspect of the process; because of the lack of clean-cut criteria, the application of these classifications is quite difficult. This is readily understandable because pegmatites, being a product of granite magmas, are composed of the same elements and basically of the same minerals, but present commonly in quite different ratios. Consequently, without a definite reference to their quantitative chemical or mineral composition, it is in effect impossible do devise a scientific classification; this quantitative aspect, without taking into account the structure and texture, can be ascertained only after a volume testing or production. Moreover, such classifications do not consider the genetic features of pegmatites; they do not reflect the conditions of formation of individual pegmatite types, nor the differences in the properties and role of the same minerals in pegmatites of different types. It should be kept in mind, that even the percent composition alone, without taking into account the textural-structural and paragenetic features, will not reveal the genetic properties of pegmatites, as witness the designation of microclinic, microcline-albitic, and other pegmatites.

It appears then, that in these types, bodies sharply differing in properties and origin are grouped together. Suffice it to say that, in one example, microcline enters the composition of pegmatite with a granitic texture, with a grain size of 1 to 2 cm^3; in another example, microcline occurs in growths with quartz, and the pegmatite is graphic; in still another, microcline forms large crystals and blocks up to several cubic meters. In addition, microcline commonly forms monomineral zones, in places tens of meters thick, traceable for hundreds of meters along both the strike and dip. Quartz, too, may occur in huge blocks and belts.

Thus, the different bulk of minerals crystallized under different physicochemical conditions, even considered alone, determine the sequence of formation of various rock-forming minerals, which, in turn,, leads to the appearance of various associations of rare elements and rare-metal minerals.

A systematic classification of the immense amount of data on the numerous pegmatite fields of the world reveals an extreme variety and complexity in the chemical and mineral composition and textural-paragenetic features of granite pegmatites within individual well-developed fields, as well as the great difference between fields in different segments of the crust. This variety is expressed in different qualitative and quantitative relationships of rock-forming, secondary, and accessory rare-metal minerals, as well as in their different relationship in space and time. At the same time, there is an amazing similarity, repetition of composition and structure of pegmatites, with only a small number of kinds of composition and structure, despite the immense spatial and temporal break in the formation of pegmatite fields.

There seems to be a definite regularity in the chemical and mineral composition of pegmatites, expressed in a progressive complexity of mineral parageneses, from vein to vein, from field to field, and from simpler pegmatites to more complex ones. As a rule, the simplest pegmatites consist of two rock-forming minerals: K-feldspar and quartz. In other pegmatites,

additional rock-forming minerals are represented by muscovite or plagioclase (mostly albite and oligoclase), lepidolite, spodumene, etc. This is also true for accessory rare-metal minerals; for example, the simplest pegmatites in structure and composition contain practically beryl alone, while others are characterized by a relative abundance of niobate-tantalates, cassiterite, pollucite, spodumene, lepidolite, petalite, etc. There are quite complex pegmatites which carry virtually all of these minerals.

No less diversified are the structural and textural features of pegmatites, closely related to their genesis. Some pegmatite bodies differ little from granites in structure and texture. Then there are graphic pegmatites, coarsely crystalline pegmatite bodies with an incipient zonation, and pegmatite veins with a well-defined zonation. In some of these bodies, rock-forming minerals are grouped in monomineral zones, with distinct replacement complexes commonly present along with the zones. Finally, there are bodies and entire fields of albite-spodumene pegmatites where the structural features and zonation are less conspicuous because of the sharply different chemical and mineral composition and the geologic conditions of their formation. It should be emphasized that gradual qualitative and quantitative transitions expressed in a regular change of structure, texture, and composition are present in these pegmatite groups. Similarities and differences between minerals of the same isomorphic series can be compared to some extent to relations between pegmatites.

All this makes for great difficulty in working out a classification and renders any classification one-sided, if it is based on a single criterion rather than on the entire gamut of criteria. It goes without saying that a differentiation of pegmatites by types is based on their variety, while pegmatite bodies within a type are grouped by the similarity of criteria on which the classification is based.

In assuming that granite pegmatites are a family of rocks, we cannot consider them apart from their mother intrusions. A view of pegmatites as links in a single evolutionary chain against a background of granite affords a better understanding of their origin and facilitates the task of classification.

Taken for the basis of a textural-paragenetic classification; i. e., the designation of types, are the different parageneses of minerals as well as structural and textural features of pegmatites. The totality of these criteria reflects the original chemical composition of pegmatite solutions, as well as the quantitative relationships of their principal minerals, and their conditions of formation. It should be kept in mind that even as a structure carries in it the implicit stages of its evolution, so does a texture show transitions from one type to another. It may be observed that a fine-grained granitic structure changes at a certain stage of its development to a block structure which in turn, as if by a concentration of microcline crystals, becomes monomineral while the quartz forms individual blocks and zones. These transitional stages are just as conspicuous in paragenetic associations.

At certain stages of development, paragenetic structural and textural features of pegmatites become so well expressed, qualitatively and quantitatively, that it becomes possible to draw boundaries between pegmatite types and to designate the place for each type in the general development of granite pegmatites.

Parageneses of rock-forming minerals, taken as a basis for designating the types, are supplemented by associated and accessory minerals, including the rare-metal ones. To be sure, the notion of rock-forming and associated minerals is a relative one; in the evolution of a pegmatite process and its types, some rare-metal accessory minerals become rock-forming, while some rock-forming minerals are reduced in rank.

TEXTURAL-PARAGENETIC TYPES OF PEGMATITES

In the following exposition, we take up the empirically established regularities in the structure of pegmatites and then we turn to a theoretical analysis of these regularities. In the description of types (Figure 1), we emphasize first the nature and relationship of principal rock-forming minerals: K-Na-feldspars (microcline-orthoclase), plagioclase (albite-oligoclase), quartz, spodumene (petalite), muscovite (lepidolite), and then the other minerals, including the rare-metal ones.

Each pegmatite type so defined and described can be illustrated by many examples from pegmatite fields of the U. S. S. R. No less abundant is illustrative material from other countries: the United States (South Dakota, North and South Carolina, California), Canada, Brazil, South Africa (Hamakvalend), Madagascar, India, Manchuria, etc.

Type I — even-grained to graphic. This type practically corresponds to granite in chemical and mineral composition. Principal rock-forming minerals are K Na-feldspars and quartz with small amounts of mica, black tourmaline (locally abundant), garnet, etc. Component minerals of this type are fine-grained, closely-knit and nearly contemporaneous. Rare-element minerals are virtually absent, and the replacement processes are poorly developed. The composition of these

pegmatites suggests the slight importance of volatile compounds in their formation.

The relative importance of Type I pegmatite veins and zones is quite different in different fields. Locally, they make up the bulk of pegmatite rocks in a given field, while some other fields contain only isolated bodies or a few zones in structurally more complex pegmatites. The ratio of the volume of pegmatite with a graphic or granitic texture to that of pegmatites with other textures varies widely from vein to vein.

There are veins made up almost fully of graphic or granitic pegmatites; in others, this rock accounts for only 5 to 10% of the total volume (see Figure 1).

Pegmatites of Type I, showing different textures (granitic and graphic), represent in effect, different stages of a pegmatitic process, with the graphic texture corresponding to a more advanced pegmatite. This pegmatite is formed under the most favorable physicochemical conditions, as witness the massive growth of its feldspar: in the words of V.I. Vernadskiy [1] "like a sponge with its pores filled with quartz". However, considering the similarity in the time and conditions of their formation, as well as the lack of sizable accumulation of rare elements in these pegmatites, we group them in one type.

The occasional phenomenon of a graphic pegmatite located in small segments near the center of a granitic pegmatite is readily explained by thermal conditions in those parts of a forming body more favorable for the crystallization of graphic pegmatites.

There are transitions between pegmatites of types I and II (block), expressed in the presence of segments of block structure in even-grained and graphic bodies.

Thus, it appears that Type I has quite a simple mineral paragenesis corresponding to granite in composition.

Type II — block. This type is quite common among granite pegmatites and is characterized by the presence of two zones. The outer zone, or "ring" (in lenticular and columnar bodies) is represented by granitic and graphic pegmatite. The other zone, mostly the central one, consists of large but non-uniform crystals and blocks[2] (from a cubic decimeter to tens of cubic meters) of K-Na-feldspars and quartz blocks; as such, it is made up of a different mineral association. In a block zone, K-Na-feldspars were precipitated much earlier than quartz, although these minerals are still not quite well separated, and form a discrete complex or zone.

Rare-metal minerals (beryl, cassiterite, niobotantalate, rare-earth minerals, etc.) occur in fairly large crystals, although, as a rule, they are uncommon and scarce. Their composition depends on geochemical features of a given pegmatite field. Some block pegmatites contain beryl alone; in others, columbite and a number of other rare-metal minerals are present. Rare-metal minerals are localized in the central zone and usually occur in quartz, being older than it. In isolated examples, rare-metal minerals such as beryl are occluded by a portion of the crystal in microcline.

Replacement phenomena are inconspicuous in these pegmatites, being expressed in small segments of mica, albite, and younger quartz, all developed on microcline of the block zone as well as in the first zone. The replacement process grows in intensity with the growth of the importance of block pegmatite in the vein's make up.

It is quite interesting to trace the origin and development of Type II pegmatites. This type always develops on the background of Type I, as is excellently demonstrated in well-exposed pegmatite bodies. It can be seen that individual segments of pegmatite veins, usually those near to the middle, exhibit larger grains within the granitic or graphic textures; this appears to be followed by a sharp break in the conditions of formation, where graphic quartz ceases to crystallize and the microcline grows alone, for a long time, with its crystals growing progressively larger toward the middle of the vein. The formation of microcline is followed by mass crystallization of quartz; in this way a true block structure is developed (see Figure 1).

In individual pegmatite veins, segments of block structure occupy an area of about 1 m^2 and even less; in better developed Type II bodies, this area is measured in tens and hundreds of square meters. Block pegmatites often form entire zones; which indicates the full development of this type.

It has often been observed in the field that block structure is often present in central parts of pegmatite veins. Conditions particularly favorable for this have been noted in bulges of medium-sized veins, in oval bodies, in bends of veins, in domes, etc., which suggest a thermal regimen favorable for a slower crystallization and a more complete differentiation.

Naturally, with an increase in the volume of segment or zones of block structure, and with

[2] Small-size block structure, with feldspar crystals and quartz bodies up to 30 x 30 x 30 cm; medium-size block, up to 1 m^3; large-size block, 1 to 3 m^3; and giant-size, over 3 m^3.

a concentration of microcline crystals, Type II progresses to Type III.

Type III — fully differentiated. Type III is the next step in the process of formation of pegmatite bodies. The latter have as many as three independent zones. The outer one, similar to that in the preceding types, consists of graphic and granitic textures, although its part in the constitution of the vein is much smaller, compared with the preceding type (see Figure 1). The middle zone is almost all K-Na-feldspar, usually microcline, locally orthoclase. The central zone is represented by massive quartz bodies of various forms, most often oval. The quartz is generally pink, because of the presence of manganese compounds, which suggests concentration of this element following an advanced and thorough crystallization. Incidentally, this suggests that other rare and dispersed elements besides manganese may have become concentrated in this process; like manganese, they virtually do not participate in the rock-forming minerals.

Rare-metal minerals are associated with the contact zone of K-Na-feldspar and quartz; as a rule, they are younger than the quartz. Some of these minerals (spodumene, beryl, tantalite, etc.) occur as crystals in the feldspar near the central quartz zone; in that event, they are older than the young varieties of microcline.

The content of rare-metal minerals in Type III pegmatites is commonly high; for each pegmatite field it is, as a rule, higher than in the preceding types. A number of veins of Type III, in some pegmatite fields, are a commercial source of beryl and spodumene (Brazilian pegmatites, etc.).

Replacement processes are better developed here than in the preceding type. The assemblage of replacement minerals occupies larger areas but does not form individual zones, unlike Type IV. These areas are made up of albite, younger quartz, and muscovite, with rare-metal minerals, garnet, etc., among them. As a rule, the replacement proceeds along the interior part of the microcline zone and in individual microcline crystals in quartz; it also affects the periphery of that zone, helped by faults along which the replacing solutions penetrate various segments of the pegmatite body.

Thus Type III is represented by different paragenetic groups of rock-forming and accessory rare-metal minerals; i.e., by a different paragenesis.

Veins of Type III are considerably less common in pegmatite fields than veins of Types I and II. As a rule, Type III is developed in larger, chiefly oval pegmatite bodies or in large bulges of thick veins. Every gradation from Type II to III has been observed. Some features of Type III appear in those pegmatite bodies of Type II where microcline crystals begin to concentrate and quartz blocks begin to differentiate, but a monomineral microcline zone is not yet formed. In this case, segments of pure quartz occur along a zone of large-size block pegmatite, usually near the middle.

Type IV — rare-metal replacement. Type IV is represented as a rule by large oval to columnar bodies, from a few to 150 m thick. Such bodies exhibit a different combination of paragenetic mineral associations, expressed in four basic individual zones (Figure 2). Three of these zones are similar to those of Type III pegmatites while the fourth is made up of replacement minerals and of relicts of earlier minerals. Type IV is represented by the best differentiated veins. In best developed bodies of this type, often in individual fields of rare-metal pegmatites with a considerable lithium content, an independent quartz-spodumene zone appears along with the above-named principal zone; it follows the monomineral microcline zone and gradually changes to a quartz core. Present in this zone, in many pegmatite fields, are amblygonite, lithiophyllite, and other lithium minerals. In its turn, the replacement zone can be differentiated into several subzones, on the basis of mineral composition and texture: quartz-muscovite-beryl, lepidolite-albite, quartz-albite, clevelandite, sugary albite, etc.

A replacement zone is developed as a rule at the contact of the monomineral microcline zone and the quartz core, with the K-Na-feldspar zone the principal object of replacement. In the presence of an independent quartz-spodumene zone, replacement processes are developed along the monomineral microcline and quartz-spodumene zones (see Figure 2). In such a case, minerals of the replacement zone carry relicts of block quartz, along with the spodumene. At times, the replacement takes place along the contact of the graphic pegmatite zone and the outer side of the monomineral microcline zone.

The replacement zone is made up of albite — usually clevelandite, muscovite, younger quartz and garnet; present among the rare-metal minerals are beryl (lithium of cesium types), often pink; niobo-tantalates (columbite, tantalite, ugandite, microlite), cassiterite, pollucite (in bodies of over 1 m^3, and in tens and hundreds of tons per vein), lepidolite, petalite, phosphates of lithium and manganese, bismuth minerals, and relicts of the early-stage minerals (such as spodumene).

The bulk of rare-metal minerals in Type IV occur at the periphery of quartz bodies and replacement zones. In veins of this type, in the

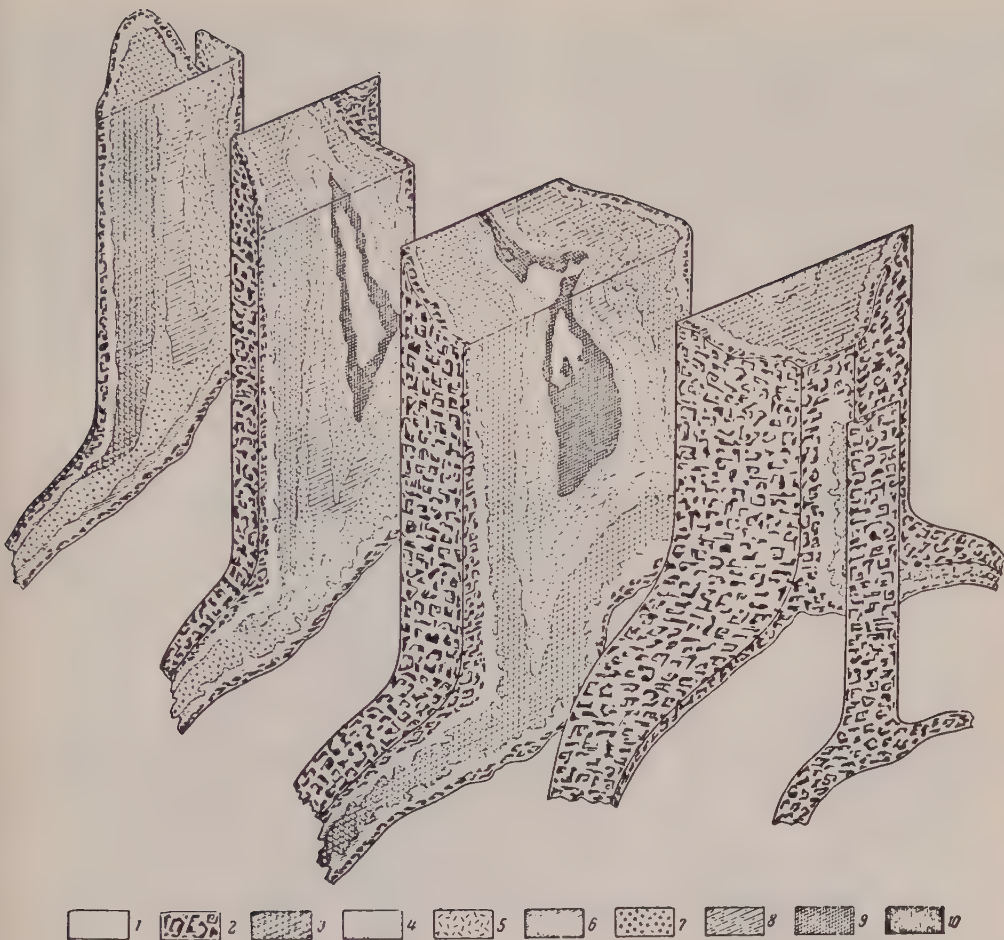


FIGURE 2. Pegmatite vein of Type IV.

1 - gabbro; 2 - zone of graphic pegmatite; 3 - monomineral and block microcline zone; 4 - block quartz zone; 5 - quartz-spodumene zone; 6 - fine-grained albite complex; 7 - quartz-muscovite complex; 8 - clevelandite-spodumene complex; 9 - thin-tabular albite; 10 - lepidolite-albite complex.

same field, more rare-metal minerals are formed at the replacement stage than is the case for Type III.

Cavities of various sizes, common in bodies of Type IV and occupied by crystals of quartz, polychrome tourmaline, lepidolite, kunzite, clevelandite, and muscovite, in an argillaceous matrix, indicate a comparatively high content of highly volatile compounds in original pegmatite solutions, as well as the presence of a high concentration of these compounds during the process of differentiation. These features also suggest the importance of later replacement solutions, partly condensed out of the volatiles, in the formation of these pegmatites.

This type is characterized by the most complex mineral composition of all pegmatites. Veins of this type carry concentrations of all rare elements and virtually all rare-metal minerals in all veins of a given field. Specifically, occurrences of precious stones in uncontaminated pegmatites, such as rose spodumene, polychrome tourmaline, rose and transparent beryl are largely associated with this type. The presence of a large number of rare-metal minerals is explained by two factors: the complexity of chemical composition of the original solutions; and by a completed differentiation process. This promotes a concentration of rare elements up to the point of their forming individual minerals in large accumulations.

Type V — albite-spodumene. This type is represented by leucocratic rocks consisting chiefly of albite, spodumene, and quartz;

unlike the preceding types, microcline occurs in subordinate amounts.

Pegmatite bodies of Type V are most commonly tabular, from a fraction of a meter to tens of meters thick, traceable for about a kilometer, occasionally for 1.5 or 2 km, along the trend, and often for over one kilometer along the dip.

Zonation is not as well expressed here as in other types (see Figure 1, 3, 4); the graphic pegmatite zone is virtually missing, and so are, as a rule, the monomineral microcline zones and individual zones or large kernels of quartz. In some examples, the initial stage of albite-spodumene pegmatite (transitional from Type IV) shows thin monomineral microcline or bi-mineral microcline-spodumene and spodumene-quartz zones. However, these zones are often camouflaged by replacement processes and are recognizable only by microcline relicts in albite, in interstices between large spodumene grains.

Albite-spodumene pegmatites are just as

FIGURE 3. Vein of albite-spodumene pegmatite.
(Drawn by I.B. Nedumov)

1 - tabular spodumene with quartz and some unevenly distributed albite; 2 - muscovite; 3 - fine-grained quartz-muscovite fringe; 4 - tourmaline; 5 - albite; 6 - quartz; 7 - coarse- to fine-grained quartz-feldspathic pegmatite with muscovite; 8 - microcline blocks. Arabic numerals in circles mark segments drawn in detail.

complex in chemical composition as the Type IV pegmatites but with considerably fewer mineral species; this is due to different conditions of formation and especially to the fact that their differentiation is not as complete as in Type IV.

Albite is represented by two generations: independently precipitated out of original solutions rich in albite components; and formed at the replacement stage, in a decomposition of K-Na-feldspars. The quantitative relationship of these two albite types in the fields investigated is obscure, as yet, pending further study. An indirect evidence of primary albite is the relatively low muscovite content in fields of this type, compared with the large amount of albite. Had the albite been formed at the expense of K-Na-feldspars only, there would have been considerably more muscovite present, but this is not the case.

Spodumene in albite-spodumene pegmatite often is an early mineral, having been precipitated with microcline, and locally earlier, in which situation it crystallizes normal to the vein walls, in tabular crystals thickening toward the central part of the vein body. Microcline in veinlets of this type is, as a rule,

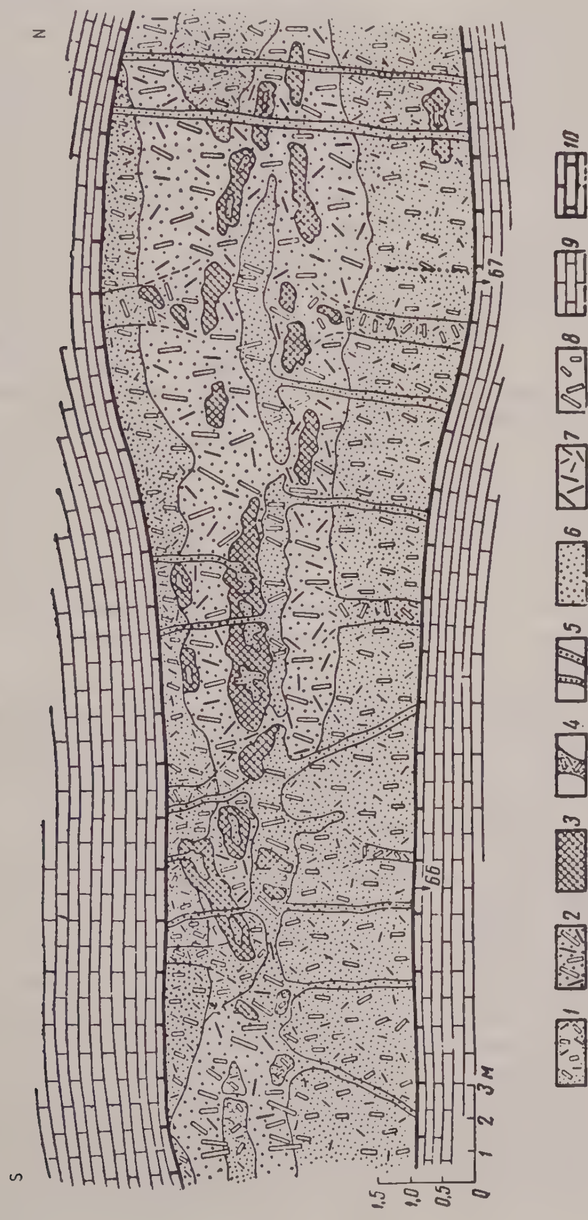


FIGURE 4. Diagrammatic sketch of an albite-spodumene pegmatite vein (Compiled by N.N. Mart'yanov).

1 - fine- to medium-grained quartz-albite-spodumene complex; 2 - coarse-grained complex of the same composition; 3 - block pegmatite (quartz, microcline); 4 - transverse veinlets of medium-grained quartz-albite-spodumene complex; 5 - quartz veinlets; 6 - quartz; 7 - albite; 8 - spodumene; 9 - marble-like limestone; 10 - marble.

grayish with blue cast and is represented by small-, medium-, and large-size blocks (up to 1 m^3). Its crystals are not as isometric as those of the preceding type, which also suggests different crystallization conditions. Quartz occurs in fine-grained and small-size block inclusions in the pegmatite groundmass; locally it also forms isolated bodies up to several cubic meters, in well developed thick bodies of Type V. Unlike the preceding types, this one carries no pink quartz, as a rule.

Albite-spodumene pegmatites have a rare-metal paragensis of their own. They are characterized by a high spodumene content, by a comparatively high and consistent beryl content, and by the presence of cassiterite, amblygonite, etc; niobotantalates are represented largely by the columbite group. On the other hand, lepidolite, pollucite, and vorob'yevite are virtually missing; this indicates, along with other factors, a relatively poor and incomplete differentiation.

Pegmatite bodies of Type V are finer-grained than the preceding types, with spodumene crystals measured in fractions of a centimeter or centimeters, rarely as large as one meter. Beryl occurs in crystals, often barely discernible by the naked eye, measured in millimeters and even in fractions of a millimeter. At the same time these pegmatites show a general and uniform coarsening of grain toward the middle of the vein.

Replacement processes are extremely important in Type V pegmatites. Minerals of the replacement complex are common throughout the pegmatite bodies.

All those features peculiar to pegmatite of Type V are determined on the whole by differences in chemical composition of the original pegmatite solution, especially by its lower potassium content and by a much higher content of Na and Li. Because of the law of active masses, this is reflected in the nature and sequence of crystallization in rock-forming minerals; graphic pegmatites are not formed, and neither is the thick monomineral zone with well expressed zones and kernels of quartz. In other words, the effect of the crystallization factor in the distribution of rock-forming and rare-metal minerals is dampened, and other conditions arise to control the behavior of individual elements, including the rare elements.

Of substantial importance in the formation of albite-spodumene pegmatites is the form of hollows which receive the pegmatite solutions; the composition of the enclosing rocks is also important. When lithium-rich pegmatite solutions penetrate mica schists, a considerable amount of lithium escapes to the lateral rocks; this is not true for marbles. As already noted, these pegmatites ordinarily show a well-expressed tabular form and are comparatively thick. In such hollows, pegmatite molten solutions cool off faster, with a correspondingly more rapid crystallization, which is not conducive to a differentiation of pegmatite bodies thus formed. It appears that when pegmatite solutions of a composition corresponding to albite-spodumene pegmatites fill up hollows of different forms, they form better-differentiated bodies approaching Type IV in structure and texture. Some veins in the Black Hills belong to such bodies (Etta-Main, Bob Ingersol).

These features of the composition of albite-spodumene pegmatites, along with their structure and texture, suggest that these pegmatites should be regarded as special bodies representing an independent line parallel to pegmatites in general. Indeed, in their extreme form, they are quite different from common non-rare-metal pegmatites which are 99.9% feldspar, quartz, and mica and are represented by rock with granitic to graphic textures. However, these two sharply different pegmatites are connected by intermediate links of all possible gradual transitions. For instance, some Brazilian pegmatites, being typical representatives of Type III, carry a considerable amount of spodumene, a typical Type V mineral. Type IV which occurs along with Type III in the same pegmatite fields (Mongolian Altai etc.), so that their genetic relations are unquestionable, carries much albite of two generations, along with spodumene (up to 150,000 tons in some veins) and other rare-metal minerals characteristic of Type V. In typically albite-spodumene fields (Southern California), pegmatites of Types III and IV occur along with those of Type V. Thus, a close genetic relationship exists for all these types, indicating both the unity and diversity of their conditions of formation.

In describing the zonation of pegmatites, no mention has been made of contact fringes locally attaining the rank of zones (see Figure 1) and at times rich in mica (up to 70% muscovite in a zone). In some veins and fields (such as the famous muscovite deposits in India), these fringes present fairly thick zones (up to 1.5 to 2 m) of high quality muscovite, commercially developed. Development of thick muscovite zones appears to be related to a certain type of rocks (micaceous shale).

Thus we have identified, from an analysis of voluminous material, five textural-paragenetic types of pegmatites. The basis of this classification is the rock-forming minerals and their relationship in space and time, i.e., structure and texture. Used for a supplementary classification criterion were rare-metal minerals common and often abundant in all pegmatites. In working-out the early variants of this classification the emphasis was on rare-metal minerals suitable for manual ore sorting, since

that was the method of exploitation of pegmatites prevailing then. In ablite-spodumene varieties, rare-metal minerals (beryl, columbite) are fine-grained; however, they must be accounted for in a classification, because of the development of beneficiation methods.

Rare-metal minerals complement the characterization of parageneses and provide means for a better understanding of the properties and formation condition of pegmatites. Thus, depending on the content of this or that rare-metal mineral, several sub-types can be identified among pegmatites of block Type II, such as beryl, beryl-columbite, monazite-orthite, pyrochlore-betafite, etc. In the same way, sub-types beryl-spodumene, beryl-columbite, monazite-euxenite can be identified in Type III; spodumene-lepidolite, petalite, lepidolite-pollucite, etc., in Type IV; spodumene-columbite, spodumene cassiterite, spodumene-beryl, in Type V; etc. The presencc of a given rare-metal mineral depends on chemical composition of the original solution and on the formation conditions for pegmatites which, in turn, are naturally determined by geochemical features and physico-chemical conditions of the mother granite intrusions.

Theoretically, it seems reasonable to assume that each of these five types has a corresponding compound practically free of rare-metal minerals.

GENERAL REGULARITIES COMMON TO TEXTURAL-PARAGENETIC TYPES

A systematic classification of extensive material allows a formulation of a number of emphirical regularities pertaining to pegmatites and to the process of their formation.

1. Pegmatites, being derivatives of granite, constitute with them a discrete chain of rock evolution, where a gradual accumulation of certain properties brings it up to a breaking point; i. e., to the appearance of individual links corresponding in nature to certain types of pegmatites (see Figure 1). It may be assumed arbitrarily that the degree of development in a pegmatite corresponds to the magnitude of its difference from mother granites. It is also true, generally speaking that the more advanced the pegmatite type, the more it differs from granite, in its composition.

2. Each preceding type carries in its final development the features of the following type; i. e., each type has its inception in the preceding type, as illustrated in Figure 1, by gradual transition between the types.

Insofar as these pegmatite types are links of a discrete evolutionary process, it is natural that present among them are all of the intermediate forms. Thus, appearing at certain stages of graphic pegmatites are features of block pegmatite, in segments having a block structure. This is particularly well illustrated in the gradual transitions from Type II to Type III; features of the latter are present in some Type II pegmatites; e. g., concentrations of microcline crystals and quartz blocks. Appearing in Type III are accumulations of albite and replacement segments; in Type IV, they merge into an independent zone; and in Type V they are developed throughout the pegmatite body.

3. The internal structure and differentiation of pegmatites becomes more definite from Type I through Type IV, following the course of their evolution. The most complex are pegmatites of Type IV where the differentiation is at its maximum. Closely related to the crystallization differentiation are the development and intensity of replacement processes which lead, in pegmatites of Type IV, to the formation of an independent mineral complex and consequently further complicate their structure. The consecutive development of pegmatite types is expressed not in the appearance of new zones, alone, but also in the great development of zones existing in the preceding types.

As the structure of pegmatites (through Type IV) becomes more complex, the size of their component minerals, rock-forming as well as rare-metal, increases. Thus, spodumene occurs in comparatively small grains and crystals, in pegmatites of the first two types, while it reaches a giant size in Type III and especially in Type IV, where it may reach a few meters and locally as much as 10 m in length. This, however, does not preclude the presence of small crystals of rare-metal minerals, especially in replacement segments and zones. It should be noted in passing that, generally speaking, replacement processes lead to the formation of mineral complexes finer-grained than those on which they are developed.

The distribution of rock-forming and rare-metal minerals in Type V pegmatites is subject to regularities of their own, because of the above-mentioned specific features of their formation. Generally speaking, the concentration of those minerals is not as well developed in their zones and blocks.

4. The relative importance of granitic and graphic pegmatites decreases going from mother granite to Type V by way of the intermediate types, with a parallel decrease in the content of microcline and orthoclase, and an increase in albite and spodumene (see Figure 1). Thus, the microcline content in graphic pegmatite is about 75%, with about 50% in Type IV and about 10% in Type V. The amount of albite grows with each consecutive type, until albite becomes one

of the principal rock-forming minerals in Types IV and V. The spodumene content ranges from practically zero in Types I and II to rock-forming proportions in Type IV and especially V.

5. Parallel to the compositional change in the rock-forming minerals, the amount and variety of rare elements and highly volatile components increases from Type I on; at the same time, the volume and number of rare-metal minerals (through Type IV) increase while their chemical composition and crystallographic aspect change [4]. Of course, the nature of rare-metal minerals as well as their amount in individual types depend on geochemical properties of each pegmatite field, although they have certain features in common.

Rare-metal minerals are virtually absent in Type I.

Type II, being less developed, exhibits the smallest number and the smallest amount of rare-metal minerals in a given field; most common here is beryl with small amounts of niobo-tantalates and rare-earth minerals. Beryl is represented by fairly large, well-formed, long, columnar crystals generally occurring in quartz. A small portion of rare-metal minerals is associated with small segments of the replacement complex.

In Type III, considerable amounts of spodumene and amblygonite appear in places along with the above-named minerals; what is more significant, a comparatively larger amount of rare-metal minerals is present in the replacement complex.

Type IV is richer in mineral species and in accumulations of rare-metal minerals. This is explained by a more complete differentiation in this type, resulting in high concentrations of rare elements in individual zones, which is what determines the formation of a large number of mineral species. Present in Type IV, in addition to the above-named elements, and locally in large amounts, are lepidolite, pollucite, petalite, microlite, columbite, tantalite, ugandite, bismuth minerals, etc. Beryl and spodumene are associated as a rule with definite zones and segments. Spodumene and quartz form locally independent zones. Most rare-metal minerals are formed in the formation of the replacement complex.

Beryl of Type IV carries considerable amounts of Cs and Li and occurs in short columns and tablets. The beryl is commonly pink because of its considerable manganese content. Pollucite, present to a considerable extent in Type IV veins, occupies a strictly defined position at the contact of the replacement zone and quartz kernel. This type is characterized by an independent finely crystalline albite-lepidolite zone located near and above the quartz kernels.

Type V carries a great volume of a limited number of species of rare-metal minerals, mostly spodumene and beryl with a small amount of columbite. As noted before, they are more evenly distributed through the pegmatite body (not counting the vertical zonation); an individual spodumene-microcline zone is present only locally at initial stages, in the transition from Type IV to Type V.

It appears that all these regularities are determined by the degree of differentiation in pegmatites as well as by other factors, active prior to crystallization.

6. Part of the pneumatolytic-hydrothermal stage grows more important in the formation of pegmatites, going from type to type, and with it grows the content of minerals (lepidolite, muscovite, pollucite) carrying water, fluorine, and other elements missing in minerals of early complexes.

One of the features which set pegmatites apart from one another is the degree of development in them of replacement processes the role of which, on the whole, also increases up to the highest type. Bodies of Type I, in their classic form, do not contain segments of replacement complexes. In Type II, replacement processes are still quite weak so that replacement complexes are unimportant in their constitution. They are associated here, as a rule, with the block microcline zone. In Type III, replacement processes are quite important, and replacement complexes gravitate toward the contact of the central quartz and the microcline zones. However, these complexes form broken-up segments of various sizes, rather than a single zone. Type IV is characterized by the presence of a thick and well defined replacement zone at the contact between the microcline and quartz monomineral zones. Locally, the replacement process penetrates other zones, as far as the periphery, by way of fractures.

In Type V, replacement processes are quite intensive, being expressed in the decomposition and replacement of K-Na-feldspars, spodumene, etc. As of now, it is hard to say in which one of these types IV and V the replacement processes are stronger, because it is hard to determine what proportion of albite, the main component of Type V, was formed at the replacement stage.

Without an understanding of these regularities common to all pegmatites, it is in fact impossible to grasp regularities in the structure of any given pegmatite body and to determine the causes of a particular paragenesis and association at any point of a vein; nor is it possible to

determine the stage of development of a pegmatite body or its genesis. It is the underestimation, by many students, of these regularities peculiar to the pegmatite family that has led to the appearance of specific qualitative and mostly local classifications (by rock-forming minerals, chemical composition, rare elements); it also has led to the failure to recognize regularities in the distribution of rare elements and to a number of erroneous genetic conclusions.

It should be kept in mind that all these clean-cut regularities in the internal structure of pegmatites and the distribution in them of rock-forming and rare-metal minerals are at times strongly distorted and camouflaged because of the elements of occurrence of veins, intra-ore tectonics, superimposed replacement processes, etc. For example, veins may be asymmetric when a single monomineral microcline zone is developed instead of the two, with the other half of the vein made up of quartz. In that event, the replacement zone naturally develops at the periphery of a vein rather than in the middle of it. In some veins, block quartz is separated from the microcline zones. The vein structure is often strongly modified by replacement processes. All this is because pegmatite solutions are a complex physico-chemical system quite sensitive to the smallest change in factors affecting the formation of pegmatites (volume, form, elements of occurrence of veins, etc.). Consequently, the field student trying to determine the structure and process of formation of a pegmatite body should be guided by regularities common to the entire pegmatite family.

BASIC FACTORS IN THE FORMATION OF VARIOUS PEGMATITE TYPES

In determining the factors affecting the formation conditions for any natural objects, including pegmatite bodies, it should be kept in mind that the formation of all bodies is determined by a combination of factors acting together rather than separately, and that this combination varies in both space and time. For this reason it is difficult to ascertain the role of any single factor because it may be weakened or strengthened by the action of the others.

The activity period for factors affecting the appearance of this or that pegmatite type may be tentatively divided into two intervals, before and after the intrusions of pegmatite solutions into the rocks. Similar parageneses may originate as a result of either type of factors; in the first instance, this is due to the degree of "carving-out" the pegmatite solution hearths at depth; in the second, to the secondary distillation of highly volatile components, including the rare-metal accumulating in the upper parts of veins; also to a favorable differentiation process.

Factors leading to the formation of pegmatite types become operative as early as the intrusion time. The original chemical composition of pegmatite solutions is dependent to a great extent on the chemical and mineral composition of the mother granite. Granite intrusions are fairly different among themselves in composition, especially in the content of rare elements and volatile compounds; this determines to some extent the chemical composition of their derivatives, as well, including the pegmatite solution. This is one of the reasons for differences in pegmatite fields formed in different segments of the crust.

At the same time, it may be assumed that granite intrusions different in their over-all chemical composition may form pegmatite fields similar in composition, under propitious thermodynamic conditions. Thus fields with rare-metal pegmatites are formed under certain conditions, in connection with intrusions rich in the corresponding rare elements (lithium, cesium, beryllium, tantalum). On the other hand, intrusions poorer in these rare elements and formed during a longer time and at proper pressures — which promotes the change of rare element compounds to the volatile state and their concentration in the hearths of pegmatite solutions — are also accompanied by pegmatites rich in rare-element minerals.

It is also quite obvious from thermodynamic and physico-chemical considerations that granite intrusions, even most alike in composition, will yield different volatile fractions under different conditions of formation (pressure, for instance). Thus only water will become volatile at a certain pressure in an intrusion; aqueous compounds of beryllium at a different pressure in the same intrusion; tin and tungsten at other pressures; and sodium, lithium, cesium, and rubidium at still others; with a combination of all in some instances. Where water alone is concentrated at the top of a granite intrusion, the subsequently formed pegmatites are marked by a simple composition and carry no rare-metal minerals. In another situation, such rare elements as Li, Be, Nb, Ta, etc., pass to the volatile phase along with water vapor, which creates conditions favorable for a subsequent formation of compound rare-metal pegmatites.

Field observations indicating the immense importance of volatile compounds in the formation of pegmatite solutions are corroborated by theoretical considerations as well as by experimental physico-chemical study. In recent years, it has been shown experimentally that rare elements concentrating in pegmatites form various simple and compound volatiles. The American students L. Grossweiner and R. Seifert [11] have determined experimentally the feasibility of transporting beryllium, as hydroxide, in water vapor. It has been shown that the volatility of beryllium rises sharply with the

vapor pressure, due to the formation of gaseous beryllium hydroxide. The same has been found true for Sn, Mo, and W; which is quite important because water is a common compound in igneous processes and an important factor in the formation of pegmatites.

Obviously, concentration conditions for highly volatile compounds in certain parts of intrusions depend on tectonic processes which take place in the formation period of intrusions and pegmatites. Tectonics determines the nature of development of pegmatites as physicochemical systems. Of great importance is the time of tectonic disturbance and the entry of pegmatite solutions into the hollows formed.

It is quite obvious that when the hearths of these solutions — formed as the result of an emanation process — remain intact (not opening up) because of the lack of tectonic disturbances, they produce the widely distributed pegmatoid facies of granite. Because of the fine-grain of this facies, a considerable portion of their rare elements is dispersed to form scattered accumulations of rare-metal minerals. There are more and more data to the effect that pegmatoid granite facies accompanying rare-metal pegmatites in some fields carry such minerals as beryl, spodumens, and columbite, thus suggesting that there are ways of forming pegmatites, other than those thought of before.

When the hearths of pegmatite molten solutions open up at an early stage, namely before the accumulation of a large amount of highly volatile compounds, they produce simpler pegmatites with a poorly developed hydrothermal phase and replacement processes. In another extreme instance, a typical greisen process takes place with the formation of later contraction fractures. All other pegmatites are intermediate between these two extremes.

The second period of pegmatite formation, beginning with the appearance of fractures and with their intrusion by pegmatite molten solutions, is no less important in the development of various pegmatite types. Of great importance here, along with the original chemical composition of pegmatite molten solutions, is the nature and interaction of other factors: emanation and crystallization. Once within a fracture, the pegmatite solutions are under lower pressure and temperature conditions. Highly volatile compounds left behind in the hollows, too, seek the segments of lower pressures and temperatures; this leads to a new vertical differentiation and creates conditions for a corresponding paragenesis — and consequently for a pegmatite type — up and down the intruded hollow.

Field observations as well as experimental and theoretical study show that crystallization is one of the most important factors in the distribution of minerals and elements in pegmatite veins, and the paramount factor in the formation of various genetic types. In a number of occasions, a well-developed differentiation process leads to accumulations of residual solutions, similar to those in well-seasoned pegmatite hearths which give birth to albite-spodumene pegmatites. The progress of the crystallization factor depends a great deal on the volume and form of the hollows where pegmatite bodies are formed [6].

Small bodies cool off faster and crystallize in a fine-grained undifferentiated rock. Under those conditions, highly volatile compounds and the replacement processes are affected in different ways than those prevailing in larger bodies, and rare elements are dispersed throughout the crystallizing rocks. There are none of those rare-metal associations (cesium-beryl, pollucite, bismuth minerals, etc.) which originate out of similar molten solutions in larger and well-differentiated bodies. In isolated examples, the formation of pegmatite types is substantially affected by the composition and nature of lateral host rocks, their reaction with the pegmatite solution, and their capacity to produce hollows of various forms to be filled up by the pegmatites.

Thus with small fractures in rocks, even those pegmatite molten solutions rich in volatile and rare-metal compounds produce only minor veins of rare-metal pegmatites, without any commercial value. An example is albite-spodumene pegmatites in the area of the famous Kolor auriferous ore deposit of India, represented by thin, extremely small veins in metamorphic schist.

The escape of sizable amounts of K, Al, Si, and other elements to the lateral rocks effects a change in the composition of pegmatites. In some instances, such as with ultrabasic rocks, the reaction of pegmatite molten solutions goes so far as to form the so-called desiliconized pegmatites, quite different in their composition from "pure" pegmatites; this strongly affects the situation of both rock-forming and rare elements [6a]. When the intruded rocks are rich in calcium, crystals and blocks of a more basic plagioclase (oligoclase) are formed in peripheral parts of pegmatite veins, as a result of assimilation. The reaction of pegmatite molten solutions with metamorphic schists leads to the formation of thick contact deposits of muscovite (India).

Described here are only the main factors in the formation of pegmatites and in the development of their types. These factors are considerably more numerous. Thus, temperature is of importance as is the nature of its decrease, the role of volatile and endothermal compounds, the heat conductance of lateral rocks, etc. A powerful factor is time; i. e.,

the duration of a process. We emphasize once more that all these factors operative in the formation of pegmatites, as of all natural bodies, act in conjunction with one another and, what is quite important, may be mutually compensating. Thus, the duration of processes of emanation concentrations for highly volatile compounds, including the rare-metal compounds, in the formation of hearths of pegmatite solutions may be compensated for, in other granite intrusions, by an abundance of these compounds.

The formation of various pegmatite types is closely related to the origin of pegmatites, in general. The theories extant on the origin of pegmatites have been discussed in our other papers [3-5]. There are two main hypotheses of the origin of compound rare-metal pegmatites. The gist of one of them is that these pegmatites are formed out of independent pegmatite molten solutions originating in granite intrusions. Other students regard these pegmatites as the result of replacement and recrystallization of granite veins and fine-grained pegmatites in a reaction with younger hydrothermal solutions.

These hypotheses are dealt with in a voluminous literature and we are not going to pause for them here [7, 10, 15]. We only note that an overwhelming majority of working geologists accept the independent pegmatite solutions as the most satisfactory explanation for the totality of facts and problems related to regularities in the origin and development of pegmatites. More specifically, this view clarifies the clean-cut regularity in the distribution of rare elements and rare-metal minerals, in both space and time, which is unexplainable by the other theory. The opinions differ, however, on how these solutions are formed.

Some students (P. Niggli, A. Ya. Fersman, and others) believe that these compounds are formed in the crystallization of mother granite intrusions, as an intergranular residue whose intrusion initiates the formation of pegmatite veins; in other words, pegmatite solutions are regarded as a product of cooling-off and crystallization of granite intrusions. To illustrate this thesis, a number of students draw various physico-chemical diagrams. However, an analysis of field material on granite and pegmatites leads to the conclusion that the concepts illustrated by these diagrams have no direct bearing on the origin of pegmatite solutions.

The vast amount of field data accumulated in recent decades suggests a different origin of such compounds, and consequently of the pegmatites themselves. The presence of pegmatoid facies in granite intrusions, locally with such rare-metal minerals as beryl, spodumene, and columbite, as well as the gradual transition in time and space from pegmatoid intrusive facies and pegmatite veins, and the occurrence of the most complex pegmatites at the top of granite intrusions, all suggests that pegmatites are facies or phases of the granite intrusions themselves, being a product of accumulation of highly volatile compounds, including the endothermal rare-metal ones, through emanation in isolated, chiefly uppermost, parts of granite intrusions.

According to our data, the main trend of the process of initiation and development of pegmatite molten solutions is related to the concentration of volatile compounds in the intrusion of granites or other igneous bodies, rather than to crystallization of mother granite intrusions. Thus, pegmatites are facies or phases of the corresponding intrusions. We believe that these concepts afford the best explanation of the origin of pegmatites in general, as well as of their textural-paragenetic types and their regularities.

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PRINCIPAL TYPES OF LOWER CAMBRIAN SEDIMENTARY FORMATIONS ON THE SOUTHWESTERN MARGIN OF THE SIBERIAN PLATFORM[1]

by

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Up to recently the attention of students of the Cambrian in the western part of the Siberian platform and along its fringe has been directed mostly to stratigraphy. The achievements in this field have provided means of correlating Cambrian sections in that region, of grasping their details, and of revealing the geologic features of the area. Most important in the last respect is N. S. Shatskiy's method of formation analysis. No such analysis for this area has been made until recently when V. V. Khomentovshiy [21] made a first step in that direction. This paper is an attempt to fill the gap, to some extent, and to shed light on Lower Cambrian sedimentary formations along the western periphery of the Siberian platform (Turikhansk region, the extreme eastern part of the Yenisey Range) and its marginal troughs (Igara area; the main part of the Yenisey Range; northwestern Sayan region; northwestern part of eastern Sayan).

For the lack of space, we cannot go into the Cambrian stratigraphy of each of these regions. Our data on that subject have been published on many occasions [4, 5, 6, 12, 14, 15, 20, etc.]. We only note that we have tentatively drawn the Lower Cambrian boundary in our sections at the base of a conformably stratified series resting unconformably on the underlying rocks and carrying Lena trilobites in its upper half and rare brachiopods and hyolites in the lower.

Over most of the area under study the Cambrian rests on Riphean sedimentary and volcanic-sedimentary deposits [7, 16, 20]. In the South Yenisey Range, the north Sayan region, and in the Mana headwaters, the Cambrian rests on crystalline rocks represented partly by strongly metamorphosed Riphean deposits and partly by older formations exposed at the onset of the Cambrian [20, 21]. Riphean deposits of these regions were accumulated in a miogeosynclinal trough extending nearly meridionally from the Igarka region in the north to the Yenisey Range in the south, and veering southeast, along the edge of the ancient Siberian platform, in the western part of east Sayan. The accumulation of Riphean sediments was followed by a phase of Baykal folding accompanied by intrusions and subsequent deep erosion.

At the beginning of the Early Cambrian, this province was again involved in the subsidence of a vast trough extending from the northwestern Sayan region and the Mana basin, across the Yenisey Range, and north to the Igarka region [15, 18, 19]. The eastern boundary of that trough was a province of relatively slow and uneventful subsidences; this area may be regarded as having been an Early Cambrian Siberian platform [14, 15, 19; Figure 1]. The outer boundary of that trough, away from the platform and within the east Sayan, was a geanticline on the site of the present east Sayan anticlinorium, which stood high during the entire Early Cambrian as a narrow cordillera and separated this trough from a eugeosyncline adjacent to it in the south [19, 20]. This boundary is also fairly definite in the north. Here an uplift occurred on the left bank of the Yenisey, west of the Yenisey Range; like the east Sayan anticlinorium, this uplift was a source of terrigenous material during most of the Early Cambrian [15]. It is probable that these two structures were merged into a single geosynclinal uplift which we have named the east Sayan.

The internal structure of the above-named trough was complex (Figure 1). A longitudinal Lebyazhinsk-Beretsk uplift, brought about by a deep fault, separated the Yenisey trough in the west from the Teya-Kana trough in the east, both being major features [14, 16, 19]. The Teya-Kana trough, which in the south changes its northwesterly trend to nearly meridional, exhibits a transverse lack of uniformity: its Solbinsk and Zherzhul synclines (the Mana basin) as well as the Tagulo-Biryusinsk region differ in the composition and thickness of their Lower Cambrian sections [18, 19].

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[1] Osnovnyye tipy osadochnykh formatsiy nizhnego kembriya yugo-zapadnoy okrainy Sibirskoy platformy i yeye obramleniya.

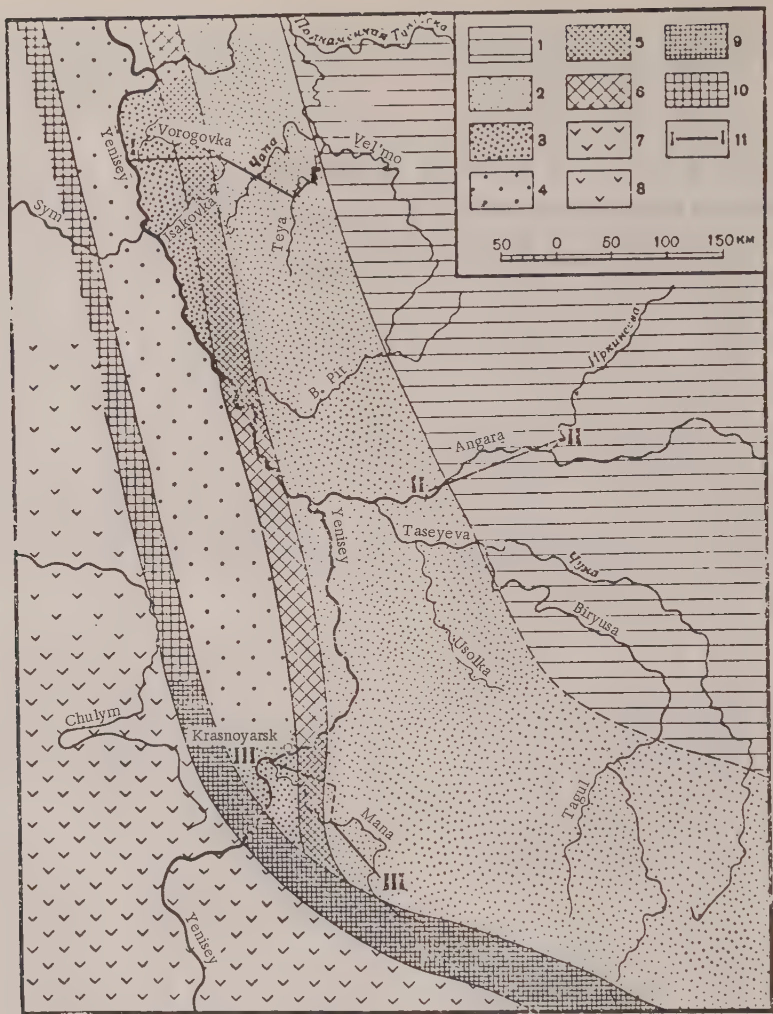


FIGURE 1. Generalized map of the distribution of principal structural elements of the Yenisey Range and northwestern part of east Sayan, in the Early Cambrian.

1 - Siberian platform; 2 - Teya-Kana trough; 3 - Yenisey trough; 4 - same, assumed; 5 - Lebyazhinsk-Beretsk uplift; 6 - same, assumed; 7 - Altai-Sayan eugeosyncline; 8 - same, assumed; 9 - Yenisey-Sayan geanticlinal uplift; 10 - same, assumed; 11 - cross-section lines.

We have based our subdivision of Lower Cambrian deposits on the descriptions by N. S. Shatskiy [22, 23].

Occurring at the base of the Cambrian in the western part of the Yenisey Range and in the eastern part of the Teya-Kana troughs (Figure 2) is a uniform paragenetic association of red to less commonly motley, terrigenous clastic deposits which may be regarded as a basal red molasse facies (Karagas, Angul'sk, Koval'sk, Lopatinsk, and the lower part of the Vorogovsk, formations, which we assign to the lower part of the Tolbinsk substage; [8, 14, 15, 20]). Its base is represented by conglomerate containing pebbles of local underlying rocks. They gradually change upward to fine- and medium-grained sandstones with lenses of small-pebble conglomerates in the lower part and with intercalations and lentils of siltstone and shale in the upper part.

These rocks are massive and coarse slaty, usually cross- and wavy-bedded, locally with ripple marks, and only occasionally thin and horizontally bedded (Lopatinsk formation). The presence of fine flat pebbles of reworked metashale is typical of the lower sandstone beds.

There are varieties of polymictic (clastic and arkosic) to quartz-feldspar and almost pure quartz sandstones and siltstones. Clastic rocks are most common in this sequence, being particularly characteristic of its lower half. They consist of quartz grains and of a considerable (locally predominant) amount of fragments of assorted local rocks underlaying the Cambrian (largely schists, quartzites, carbonates, and some extrusive rocks). Arkosic sandstones have been observed at the base of the Cambrian only where it rests on granite and gneiss. Extensive pure quartz sandstones (locally with kaolinite) have been observed in the upper half of this sequence, in the northeastern part of the Yenisey Range. In the Sayan region, this part of the section is made up of peculiar quartz-feldspar siltstones which are 70% K-feldspar. The thickness of this sequence ranges from 1200 to 1500 m in the part of the Teya-Kana trough most remote from the platform (Upper Mana) to several hundred meters on its near-platform slope (Taseyeva River, the lower course of the Tana) and 20 to 100 m on the western margin of the Siberian platform (Irkineyeva, Man'zya Rivers). In more northern (Turukhansk uplift [5]) and interior (Chadobetsk uplift [2]) parts of the platform, the basal red molasse member is missing.

Appearing within this sequence in the southern and the widest part of the Teya-Kana trough is a dolomitic facies of the Bogatyrsk type. Its main component is fine-grained to aphanitic pink, gray, straw-colored, and dark-gray dolomite. It is usually thin-bedded, in places cross-stratified, locally sandy, and often stromatolithic. Occurring locally are lenses of dark chert; present in the lower part, along Biryusa River, is a unit of motley siliceous dolomite with layers of basic extrusives. The Bogatyrsk dolomite carries beds and isolated lentils of terrigenous rocks which are components of the adjacent basal molasse member. This dolomitic member is from a few tens to 500 m thick.

As already mentioned, both of these members appear to have been deposited in very shallow water. Judging from the composition of clastic material in the basal molasse facies, its main source was the Yenisey-Sayan and Lebyazhinsk-Beretsk uplifts. Only in the platform part of the Teya-Kana trough is there evidence of a sediment source on the Siberian platform.

A substantially different and more diversified facies composition prevails in overlying deposits of the Oselochnyy, Kigensk, Anastas'insk, Aleshinsk, Chividin, and Vorogovsk formations, which make up the upper half of the Tolbinsk substage. These deposits are much more extensive than the underlying Cambrian sequences and are characterized by a number of common features: a gray to green-gray color; a conformable position over the basal molasse sequence, where the latter is developed, and unconformable on the Precambrian throughout the rest of the Teya-Kana and Yenisey troughs [6, 8, 12, 13, 14, 15, 19, 20].

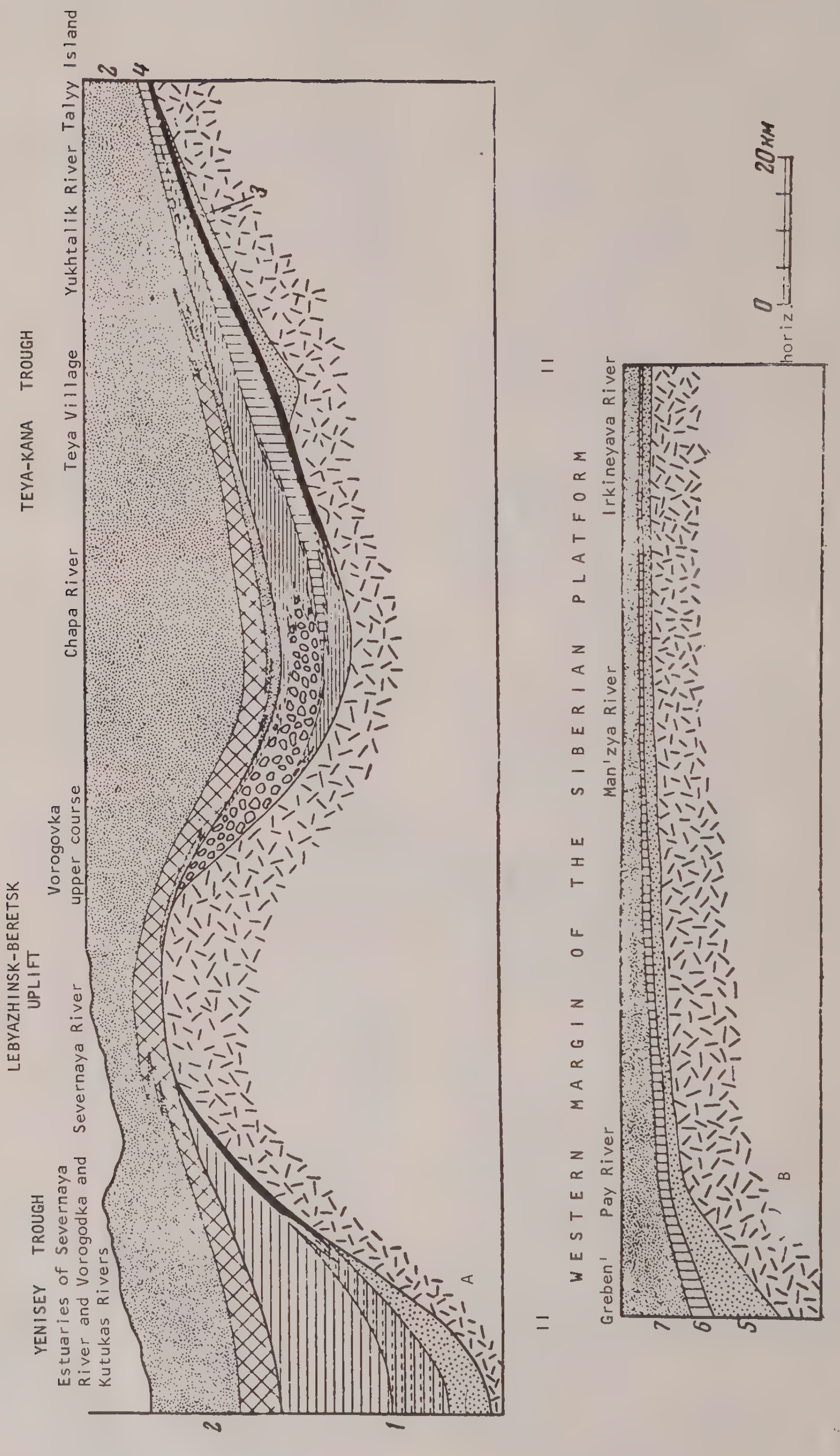
The horizontal series of members of the gray sequence is best illustrated by a cross-section in the northern part of the Yenisey Range (Figure 2-A). Here, in the axial part of the Teya-Kana trough, along the middle course of Chapa River, the entire Chivinda section is represented by terrigenous flysch. In its lower part the flysch is a rapid alternation (every 5 to 10 cm) of thin polymictic calcareous siltstones of a lithoclastic composition, and shale. These rocks often exhibit graded bedding, various hieroglyphs, submarine slump folds, and other typical flysch features. The aspect of the flysch changes toward the top [3] where it is made up of thick (2 to 7 m) beds of polymictic sandstone with horizons, up to 30 m thick, of the same sandstones rapidly alternating with siltstones and shales, in simple rhythms (5 to 20 cm).

Sandstones and siltstones of the flysch member are polymictic, with predominant, poorly rounded to angular grains of quartz, feldspars (chiefly acid plagioclase), mica scales, and fragments of microquartzite, carbonates, and basic extrusives. Typical of them is a high content of the pelitic fraction which forms a groundmass of the argillaceous-carbonate cement (locally with chlorite).

The flysch member is 800 to 1200 m thick in the axial part of the Teya-Kana trough. To the east toward the platform, this member generally thins down and is replaced by two different members, present in the axial part as individual beds and thin horizons in the flysch.

The lower of these, which we have designated the Tal'sk-type dolomitic member, is represented by assorted dolomite: oölitic, oncolithic, stromatolithic, locally with an addition of quartz sand grains and occasional glauconite. Very characteristic of these dolomites are intraformational erosion surfaces with thin intraformational conglomerates. This member is over 300 m thick, in the axial zone, decreasing to 30 m toward the platform.

Above that, there is an areno-argillaceous glauconitic member, generally developed over the same area where it replaces the flysch. It consists of light-gray quartzitic sandstone, fine to medium grained, locally coarse grained to gravelly, which form beds 0.5 to 5.0 m thick, alternating with sandy and slaty shale, 2 to 5 m thick. The sandstones are quartzose, with local additions of kaolinite and occasional glauconite. They are characterized by wavy to less-common wedge-like stratification and by knobby bedding surfaces. The shales are


YENISEY TROUGH
Estuaries of Severnaya River and Vorogodka and Kutukas Rivers
LEBYAZHINSK-BERETSK UPLIFT
Severnaya River
Vorogovka upper course
TEYA-KANA TROUGH
Chapa River
Teya Village
Yukhtalik River
Talyy Island
A
II
WESTERN MARGIN OF THE SIBERIAN PLATFORM
Greben'
Pay River
Man'zya River
Irkineyava River
B
0
20 км
horiz.

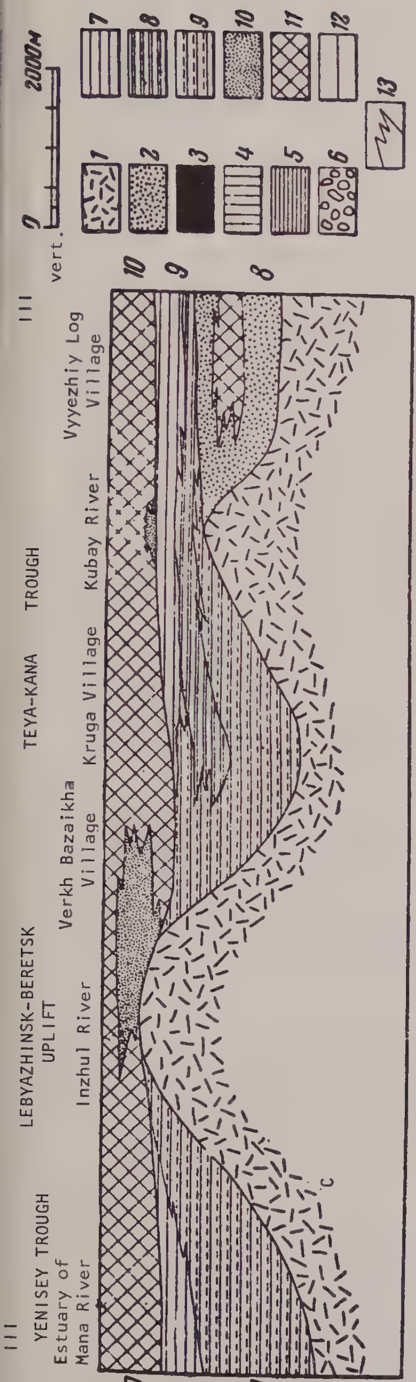


FIGURE 2. Diagram of facies relation for the Aldanian stage. A - northern part of Yenisey Range; B - southeastern part of Yenisey Range; C - basin of Mana River (northwestern part of east Sayan).

1 - Precambrian; 2-11 - facies of the Aldanian stage: 2 - basal red molasse; 3 - dolomitic beds of the Tal'sk type; 4 - glauconitic areno-argillaceous rocks; 5 - flysch; 6 - boulder-pebbly shale; 7 - calcareous slaty beds; 8 - slaty beds; 9 - graywacke; 10 - upper red molasse; 11 - dolomitic beds of the Bogatyrsk type; 12 - formation boundaries; 13 - facies boundaries. Figures in diagram designate formations 1 - Vorogovsk; 2 - Nemchansk; 3 - Lopatinsk; 4 - Chividinsk; 5 - Koval'sk; 6 - Al'shinsk; 7 - Shalyginsk; 8 - Angul'sk; 9 - Anastas'insk; 10 - Leybinsk subformation of the Zherzhul'sk formation.

usually dark-gray to black, schistose to various extents, micaceous, with many thin (0.5 to 5.0 mm) lenticular laminae of fine-grained gray sandstones, with occasional small siderite nodules. The thickness of this member ranges from 500 m in the axial part of the Teya-Kana trough to 180 m on its eastern slope. Present in these terrigenous rocks in the east are isolated beds of sandy dolomite which are an erratic member of this sequence.

An idea of changes in this section in a portion of the Siberian platform adjacent to the Yenisey Range can be obtained from the lower Angara region. Here, similar areno-argillaceous deposits thin down to 30 to 60 m (Figure 2-B) with an accompanying marked increase in the importance of sandy dolomite. As a result, this member approaches the Tal'sk-type dolomites in the genesis of its rocks. Contemporaneous intervals in the more northern and eastern areas of the Siberian platform are characterized by assorted dolomites of the Tal'sk type (Platonovsk, Tolbinsk, and Yudomsk formations) which make up the lower part of an evaporite salt-carbonate member. Only locally present among them are glauconitic quartz and arkosic sandstones.

Away from the platform, the flysch member is replaced by peculiar boulder-pebble shales. Their easternmost outcrops occur from the middle Chapa course where they wedge into the flysch (Figure 2-A). West of there, nearer the Lebyazhinsk-Beretsk uplift, the flysch is gradually and completely replaced by boulder-pebble shale [6], the main unit of which is a massive drab-gray, locally reddish to green-gray areno-argillaceous sequence with unevenly distributed pebbles, boulders, and blocks of assorted rocks of various

forms, sizes, and degree of rounding. Boulders and pebbles usually account for 15 to 20% of the total rock, their volume sharply increasing at the base, near the remnants of ancient relief. They consist of various Precambrian rocks occurring in the northern part of the Yenisey Range (limestone, dolomite, quartzite, assorted metashales, extrusive rocks, etc.), in quantitative ratios sharply differing from place to place. On the whole, there does not seem to be any regularity in the change in composition, except at the base where they reflect the composition of the underlying rocks. Locally occurring among these boulder-pebble shales are minor units of graywackes and thin layers and lenses of basic extrusives and tuffs. This member occurs on the eastern slope of the Lebyazhinsk-Beretsk uplift, extending parallel to it for over 150 km.

The Chivinda boulder shales of the Yenisey Range are regarded by most students as tillites. Our study of these deposits contradicts the hypothesis of their glacial origin [6]. We believe them to be peculiar marine fans. Large fragments and pebbles, formed at the foot of rocky cliffs of a Lebyazhinsk-Beretsk cordillera, were distributed along the trough slope by high density currents.

In the light of present concepts of the origin of flysch and boulder-pebble shales, their presence in the Chivinda deposits [6, 17, etc.] suggests a typical, contemporaneous, uncompensated subsidence in the northern part of the Yenisey Range, in the axial zone of the Teya-Kana trough. It was filled up by polymictic material brought in largely by density currents, originating on the Lebyazhinsk-Beretsk uplift.

The Tal'sk-type dolomites as well as the glauconitic areno-argillaceous sequence on the eastern, platform slope of the Teya-Kana trough were deposited under different conditions in shallow water. The definite occurrence of pure quartz sandstones along the platform slope of the trough indicates their platform source. The western margin of the platform appears to have been a site of local uplifts above sea level.

Deposits contemporaneous with those described above are missing at the arch of the Lebyazhinsk-Beretsk uplift, with the Nemchansk and Lebyazhinsk formations resting directly on the Precambrian. In the Yenisey trough, west of the uplift, older Lower Cambrian deposits of the Vorgovsk formation [15] reappear below the Nemchansk formation, conformable with it. Resting at the base of the latter and unconformably on the Precambrian, on the eastern slope of the trough, near the uplift, is a Tal'sk-type dolomite member (60 to 80 m thick) similar to that on the eastern slope of the Teya-Kana trough. Resting above them, and representing the bulk of the Vorogovsk section, are slaty limestones, fine-grained to aphanitic, and thin-bedded. They contain intercalations and lenses (0.1 to 1.0 cm) of fine-grained, green-gray graywackes which give to the rock a peculiar banded aspect; also rare and thick beds of the same limestones. This member is 500 to 600 m thick in eastern sections. To the west, dolomites and the lower third of the Vorogovsk limestone are replaced by almost massive polymictic graywackes, designated as the graywacke member. They are greenish to blue gray, fine grained, consisting of angular grains of quartz and feldspar (mostly acid plagioclase), also fragments of microquartzite, groundmass of extrusives, fine-grained limestone, and mica scales. The cement is argillaceous to argillaceous-calcareous, commonly with chlorite. Some thin sections show grains of a phosphate mineral (3 to 5%). As a rule, the graywackes form beds 1.5 to 5.0 m thick (locally up to 12 m), separated by thinner silts and shales with limestone in the upper part. Occurring in this rhythmically stratified section are massive beds of graywacke, up to 60 m thick. Common in these rocks is a distinct wavy stratification along with evidence of submarine slumping; gradual stratification is locally present; it is best expressed along Isakovka River where there is an alternation of gravel, sandstone, siltstone and local shale, in simple rhythms 0.5 to 1.5 m thick. Each element of this rhythm is from 5 to 40 cm, with the gravel the thickest component. The graywacke member is 600 to 800 m thick, in western sections; the overlying slaty limestones are up to 2000 m thick (Figure 2-A).

The presence of gradual stratification in graywacke, and of evidence of slumping in limestone, suggests that their deposition, as well as that of the flysch, took place in an uncompensated trough. Shallow-water conditions prevailed only on the eastern limb of the Yenisey trough, for some time, as witness the Tal'sk-type dolomite.

The replacement of slaty limestone by graywacke, in the west, indicates that the Yenisey-Sayan uplift was the main source of clastic material. The Lebyazhinsk-Beretsk uplift, the source of clastic material in the Teya-Kana trough, was not its source for the Yenisey trough.

Main components of this gray sequence in the Yenisey Range are typical of the contemporaneous deposits for the entire area under study. A new slaty member appears between the graywacke and the slaty limestone members of the Anastas'insk formation [13, 21] in the Mana basin. Its main components are black slaty shale and intercalations of graywacke and black limestone. A gradual change from the graywacke to slaty members, and on to slaty limestone, is easily traceable within the Mana synclinorium, away from the

Lebyazhinsk-Beretsk uplift and to the axial part of the Teya-Kana trough. This transition is typical only for the southern part of the trough and is missing, as we have seen, in the Yenisey Range. We believe that slates are characteristic of the central part of broad uncompensated troughs in contrast to the narrow flysch ones. Density currents, carrying coarse material from slopes of uplifts, did not reach that far, as a rule, and only clay particles were deposited here.

In the south, flysch is developed only in the northwestern Sayan region, and that in a somewhat modified aspect. Appearing here among rhythmically stratified terrigenous rocks are thick sandstones with a rough, wavy stratification. The hieroglyphs and evidence of slumping are less conspicuous, and boulder-pebble shales closely associated with flysch are missing. All this was probably due to a downwarping of this zone, slower than in the flysch trough in the northern part of the Yenisey Range.

These members change vertically to substantially different paragenetic associations of the Nemchansk, Shalyginsk, lower part of the Zherzhul'sk, upper part of the Olechnaya, and Ust-Tagul'sk formations, which we have assigned to the Zhurinsk substage [14, 15, 17, 19, 20].

We shall consider these members in the same way, beginning with the northern part of the Yenisey Range. Here, overlying the Teya-Kana flysch and the Yenisey trough slaty limestone, is motley molasse and the Bogatyrsk-type dolomite closely associated with it at its base. The motley molasse is not developed everywhere; it wedges out from west to east in the axial part of the Teya-Kana trough. It consists chiefly of gray, pink, and red dolomite, more or less sandy, carrying beds of the adjacent member: red wavy-bedded sandstone, siltstone, shale, and locally (upper course of the Chapa) coarse conglomerate. Near the Lebyazhinsk-Beretsk uplift, these dolomites are replaced to various extents by sandstone and gravel; however, they overlie the uplift, over a considerable distance, making up the base of the Cambrian here. Characteristically, in the Yenisey trough, these dolomites carry numerous nodules, lenses, and even beds up to 25 m thick, of black nodular chert. The dolomitic member is usually 200 to 800 m thick, locally attaining 1200 m (Isakovka River).

The red molasse is more extensive. Along the east side of the Teya-Kana trough, it rests directly on the flysch and glauconitic areno-argillaceous members, replacing the Bogatyrsk-type dolomite; it overlies the latter over the rest of the area (Figure 2-A). Its basic component is cherry- to brick-red and brown, coarse- to medium-grained sandstone, usually with rough cross- to wavy stratification and ripple marks. Occurring among sandstones in the lower part are beds and horizons of sealing-wax red siltstone and shales, alternating, as a rule, in an irregular way. Reworked flat pebbles of these rocks are common in the sandstone.

In the Yenisey trough to the west, conglomerates 5 to 10 m thick, alternating with 10 to 30 m thick sandstone beds, become important in the paragenetic association, along with the sandstones. Conglomerate pebbles are represented by quartz and quartzite, less commonly by granite, well rounded, from one to 20 cm in diameter. Conglomerates wedge out to the east where lentils rich in small pebbles of quartz and quartzites occur only in the upper third of the sandstone section of the Teya-Kana trough. Polymictic lithoclastic varieties with a greater amount of quartz compared with the underlying terrigenous sequences are present among sandstones and siltstones. Besides quartz, the sandstone contains feldspars (microcline and acid plagioclase); fragments of microquartzite, quartz-sericite, quartz-chlorite, and other schists; and mica scales. The cement is usually regenerated quartz, less commonly ferruginous or carbonate. Oligomictic quartz sandstones, externally undistinguishable from the polymictic, appear near the top.

Judging from the lower Angara sections, a lithologically similar rock association is developed beyong these troughs also, in the adjacent part of the Siberian platform, as far as the Chadobets trough [2, 14]. However, its thickness here (150 to 200 m) is much smaller than the trough molasse, which is 1000 to 3500 m. It should be noted that a thin upper molasse member in the Siberian platform is developed only east of the Yenisey Range. In other areas, contemporaneous terrigenous deposits do not penetrate that far toward the platform; they are replaced by carbonate rocks which differ from those of the Lena stage only in their motley colors, and form together with them and with the underlying Tolbinsk deposits, a discrete evaporite salt-carbonate member.

Evidence of shallow water, together with the tremendous thickness of molasse in the trough, suggest that the latter again became compensated. Judging from changes in the granulometric composition of the upper molasse member, the main source of their sediments within the Yenisey Range was the Yenisey-Sayan uplift. On the other hand, the Lebyazhinsk-Beretsk uplift was submerged to a considerable extent and was reflected as a positive structure only in a change in thickness. It appears to have stood high only in the northern part of the Yenisey Range, which is what determined a transgressive overlap of the overlying Lebezhinsk formation directly on the Precambrian [15].

It is readily seen that the upper red molasse member is genetically similar to the basal red molasse member. This similiarity is emphasized by facies relations of the two with the Bogatyrsk-type dolomite. Differences between the basal and upper molasse are chiefly the presence in the upper of typical basal conglomerate and a substantial content of terrigenous material derived from the platform.

The upper red molasse is typical of Zhurinsk deposits in the Yenisey Range [14, 15] of the northwestern Sayan region [18], and Igarka area [3]. This member is reduced in the Mana basin, where Bogatyrsk-type dolomite (deposits of the Leybinsk substage, the Zherzhul'sk formation, [19, 20] prevail in both troughs. Minor trains of molasse are developed only near the Lebyazhinsk-Beretsk uplift and a fulat which separated the Solbinsk and Zherzhul'sk synclines (Figure 2-C); unlike the Yenisey Range, gray, green-gray, and pink hues prevail here. Appearing in extreme western sections of this member are basic and intermediate. In the Mana basin, the Bogatyrsk member is 400 to 800 m thick, with the molasse 300 to 600 m.

Resting on the upper molasse (the Yenisey Range, northwestern Sayan region) and Bogatyrsk formations (the Mana basin) are paleontologically part of the Lena stage. They have survived erosion mostly within the Teya-Kana trough and on the Siberian platform; they have been almost fully obliterated in the Yenisey trough and Lebyazhinsk-Beretsk uplift.

The Lena stage deposits are represented largely by chemogenic rocks, mostly limestone, dolomite, and varieties of a mixed dolomitic-limestone composition with some anhydrite-dolomite, gypsum, anhydrite, and occasional salt. These rocks and their combinations change from one to another, both laterally and vertically, in a regular and very gradual sequence, they are in fact facies within a discrete evaporite salt-carbonate series the extreme members of which are limestone and salt (including probably potassium salts, as well). Strictly speaking, this member of the Lena stage is developed almost all over the Siberian platform, as well as on its fringe, and differs only in thickness within different structures. It was formed in a vast shallow epicontinental basin, under arid conditions, and with a one-sided compensatory inflow of sediments [1]. Shallow deposition is suggested by the well-preserved stromatolithic, oncolithic, oölitic, sedimentary breccia, with ripple marks and other such structures. The deposition of salt occurred in a single evaporite basin, the farthest removed from marine sources of standard salinity [1]. Preservation of salts in section, and accumulation of thick salt-bearing deposits was possible only in areas of active subsidence, the axial parts of the Teya-Kana trough. Here, in the Usolka River basin, three thick gypsiferous and saliniferous sequences appear among the dolomites; they are separated by dolomite and anhydrite-dolomite. In the southern part of the Yenisey Range and in the Mana basin, these deposits carry considerable terrigenous material. The thickness of salt-carbonate deposits in the Teya-Kana trough is about 2000 m, decreasing to 900 m on the western margin of the Siberian platform and Lebyazhinsk- Beretsk uplift.

Within the area under study, these rocks are unconformably overlain by younger formations, marking a new stage in the development of Baykal rocks of southwestern Siberia. In the Mana basin (east Sayan) these are thick (over 4 km) red sandstone and conglomerate series of the Badzhey and Narva formations with pebbles of assorted Cambrian rocks and of granitoids that cut them; in the northern Sayan region, these are unsorted sandstones with conglomerate lenses; and in the Kana region, there are Upper Lena sandy marls (Evenkiy formation), 1000 to 1500 m thick. These deposits, Upper Cambrian to Lower Ordovician, rest erosionally on Lower Cambrian or Precambrian rocks (Badzheysk formation). They can be assigned to the red continental molasse.

A correlation diagram for these formations within principal Lower Cambrian structure of the area is presented in Figure 3.

According to their position in the series, these formations can be divided into primary, determining the trend of the entire series; and secondary (designated by numbers in Figure 3) sporadically appearing within and among the primary beds. In this classification, secondary formations in one series are primary in another series. We assign to secondary formations of the Yenisey and Teya-Kana troughs and of the Lebyazhinsk-Beretsk uplift, the Tal'sk- and Bogatyrsk-type dolomitic members, the slaty member, and the boulder-pebble shales. In the western margin of the Siberian platform, however, the Tal'sk-type dolomitic member, as part of the salt-carbonate section, is primary in the platform formation series. Conversely, the two molasse members, primary within the trough, become secondary upon passing on to the platform, being alien to it.

Figure 3 shows that each of the main Lower Cambrian structural elements in this area is characterized by a vertical formation series of its own. The western margin of the Siberian platform is characterized by the following vertical series:

Dolomitic of the Tal'sk type → Glauconitic areno-argillaceous → Upper Molasse → Evaporite salt-carbonate (without salt)

In extreme southwestern sections, this series is underlain by a thin basal red molasse unit, not typical of the platform, being associated with the Teya-Kana trough. Going east, the upper molasse and the glauconitic areno-argillaceous members wedge out, so that a single evaporite salt-carbonate member prevails in the Lower Cambrian of the central and southern parts of the platform. Conversely, going away from the platform toward the Altay-Sayan eugeosyncline, a progressive complication takes place in the vertical series.

The following series are associated with the Teya-Kana trough:

Basal red molasse → Flysch → Dolomitic beds of Bogatyrsk type → Upper red molasse → Evaporite salt-carbonate (with salt and sulfates)

Associated with the Yenisey trough are the following:

Basal red molasse → Graywacke → Slaty → Slaty-limestone → Dolomitic of Bogatyrsk type → Upper red molasse → Evaporite salt-carbonate

Finally, the adjacent eugeosyncline is characterized by an extremely complex series of extrusive and sedimentary formations whose description is beyond the scope of this work.

This formation analysis gives a better idea of the stages of development for the southwestern part of the Siberian platform and its fringe, in Early Cambrian time.

The deposition of the basal red molasse marked the initial stage in the formation of Cambrian structures, when two long and narrow troughs were superimposed on a Precambrian peneplain. The situation in the Mana basin demonstrates clearly that their origin was associated with movement along deep faults, as early as the Proterozoic [19, 20]. The same relationship appears to be true for northern segments of these structures, as well [15, 16]. From their very inception, these troughs appear to have been asymmetric, with coarser and thicker basal molasse deposited on their outer sides, away from the platform and near the Yenisey-Sayan and Lebyazhinsk-Beretsk uplifts. This section was formed out of sediments eroded from those uplifts, which is particularly obvious for the Angul'sk and Karagas conglomerates [19, 21]. Dolomites of the Bogatyrsk type were deposited within the molasse member when the influx of sediments slackened. The most intensive subsidence within the Teya-Kana trough was localized where its trend changed from nearly meridional to southeasterly (Figure 1). These subsidences also involved the adjacent part of the Siberian platform where the same member, greatly reduced in thickness, was deposited (20 to 100 m compared with 1000 to 1500 m in the trough).

Subsequent history of the Teya-Kana and Yenisey troughs is marked by their widening at the expense of the adjacent uplifts. This widening, in conjunction with a higher intensity and differentiation of tectonic movements, was most active in Tolbinsk time; this is what brought about the appearance of uncompensated troughs (deposition of flysch, boulder-pebble shales, and graywacke slates of the Chivinda and Anastas'insk formations) as well as of lateral facies (see Figures 2 and 3). The above-mentioned asymmetry of structures became even more pronounced in Tolbinsk time. Deposited on the east, the platform side of the Teya-Kana and Yenisey Range were shallow platform members (glauconitic, areno-argillaceous, and dolomitic of the Tal'sk type), while deep-water flysch facies were deposited on the outer west side. Boulder-pebble shales were deposited on the platform slope of the Lebyazhinsk-Beretsk uplift, with carbonate facies (dolomitic beds of the Tal'sk type and slaty limestone) deposited on the opposite side. At the same time, much clastic material was brought in the Yenisey trough from the platform slope of the Yenisey-Sayan uplift; that was reflected in the asymmetry of the graywacke member. This asymmetry is not as conspicuous but still quite definite in the western part of east Sayan. It must not be overlooked that here, unlike the Yenisey Range, graywackes were associated with the Lebyazhinsk-Beretsk rather than with the Yenisey-Sayan uplifts. This indicates that the relative importance of these uplifts as sources of sediments was different for different areas and periods.

During Zhurinsk time (Nemchansk, Shalyginsk, and Izluchinsk formations) a rapid and radical equalization of conditions occurred in the several zones, in addition to a further absorption of uplifts separating the troughs. The Lebyazhinsk-Beretsk uplift to the east was fully submerged, as early as the onset of Zhurinsk time. This is well demonstrated in the Yenisey Range and the Mana Basin [16, 19],

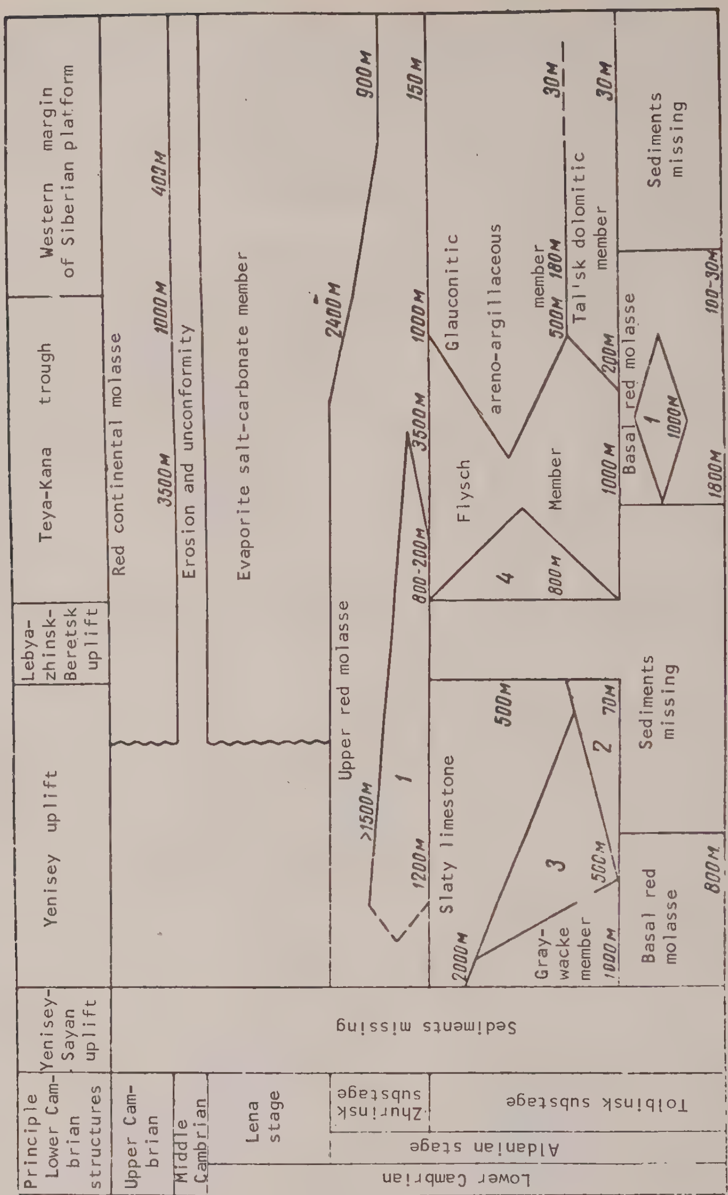


FIGURE 3. Main types of Lower Cambrian sediments on the southwestern margin of the Siberian platform and its fringe.

Numbers designate members: 1 - dolomitic of the Bogatyrsk type; 2 - dolomitic of the Tal'sk type; 3 - slaty; 4 - boulder-pebbly shale.

and was brought about by an abrupt reduction in clastic material (deposition of Bogatyrsk-type dolomites). In the southern part of the area, this stage — evidently related to a halt or a slowing down in the progress of the above-named uplifts — continued during all of Zhurinsk time. Over the remaining and larger part of the area, this slowing down was followed by an intensification in the Yenisey-Sayan uplift and by the influx of an immense amount of coarse clastic material which formed the upper red molasse. The volume of this material was so great that it fully compensated for the subsidences of the trough and "spilled out" to the adjacent part of the Siberian platform.

It should be noted that although the western margin of the Siberian platform, the Teya-Kana and Yenisey troughs and Lebyazhinsk-Beretsk uplifts, persisted as major structures in Nemchensk time, they no longer controlled the distribution of facies let alone full series, but were overlain by the upper red molasse, alone. However, the red molasse varies in thickness, from zone to zone, by a factor of 15 or 20.

In Lena time, a further equalization of conditions took place. The Yenisey-Sayan uplift ceased to be a source of sediments almost along its entire length, and its southern part was locally submerged; this led to the appearance

of geosynclinal trilobites in the Mana synclinorium [12, 20]. Saliniferous carbonates of the evaporite series were deposited throughout the area. Significantly, their thickness from zone to zone varies by a factor of but 2 or 3, incomparably less than for the underlying deposits.

The deposition of saliniferous carbonates was followed by a considerable break in sedimentation, embracing most of the Middle Cambrian. At the opposite side of the Yenisey-Sayan uplift, in the Altay-Sayan province, a typical eugeosyncline developed during the Early and Middle Cambrian, with its characteristic sedimentary section. Geosynclinal development ended there as late as the Upper Cambrian [20].

This contemporaneous development of the Teya-Kana and Yenisey troughs, on one hand, and of the adjacent eugeosyncline on the other, is the main argument against these two troughs being marginal [15, 19, 20]. A comparison of vertical series in these troughs with series of the Siberian platform brings forth sharply the substantial differences in these structures and militates against the two troughs being of a platform types. Specific features of their development, their structural position, and their sediments, testify to the fact that they were miogeosynclines, as defined by M. Kay, during the Early Cambrian.

Thus, the tenor of Early Cambrian geologic history of the southwestern fringe of the Siberian platform was a widening of its troughs at the expense of uplifts separating them; as well as the accompanying differentiation, followed by equalization, of tectonic conditions, which ended with a folding and with a confinement of geosynclinal conditions. Upper Cambrian molasse and Ordovician and Silurian terrigenous-carbonate deposits closely related to them mark a new stage in the development of the entire area.

It is interesting to compare formations of the southwestern miogeosynclinal fringe of the Siberian platform with those of a late Proterozoic miogeosyncline of the west Baykal region, discussed by V. G. Belichenko [6].

Occurring at the base of that section is a terrigenous member comparable with our basal molasse. Locally associated with it in a secondary way is a dolomitic facies similar to our Tal'sk dolomites. Above that, there are closely related carbonate-terrigenous, and carbonate members strongly reminiscent of a graywacke-slate-limestone series. Stratified phosphorites [9, 10] are present among them on the slopes of interior uplifts in the west Baykal region, locally associated with extrusives. These formations change upward to a flysch-like sequence. Present among the overlying Lower Cambrian deposits are molasse-like and evaporite salt-carbonate formations similar to ours [11].

This similarity in formations of miogeosynclines of the southern and southwestern fringe of the Siberian platform suggests a possible similarity in the distribution in them of commercial minerals, primarily phosphates. If this is true, the most prospective in that respect will be members of the graywacke-slaty-limestone series (particularly the slates and slaty limestones) on the slopes of the Lebyazhinsk-Beretsk and Yenisey-Sayan uplifts, associated with which are, as noted before, the isolated manifestations of late Proterozoic and Early Cambrian extrusive activity.

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CRYOGENIC GEOCHEMICAL FIELDS IN THE PERMAFROST ZONE[1]

by

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In methodologic works on geochemical prospecting for mineral deposits [8], especially for non-ferrous and rare metal ores [4], there has not been enough emphasis put on special conditions and specific processes of secondary concentration of elements in the soil and lithosphere of permafrost areas. For a long time, the geochemists paid no attention to regularities in the weathering of frozen rocks and to migration and concentration of non-ferrous minerals in unquestionable permafrost areas. This gap in geology was only partly filled by works of Yu. A. Bilibin [2] and N. A. Shilo [14].

The geochemists have not yet determined the specific features of migration and the dispersion haloes for rare elements in soils underlain by extensive frozen sequences slightly, if at all, permeable to water and gases. Ore deposits not cropping out at the surface of a nearly unbroken expanse of permafrost are not reflected in the chemical composition of soil to the same extent as they are under standard conditions of geochemical prospecting. Experience in geohydrochemical methods of exploration of ore deposits in areas of unquestionable permafrost has been gained in west Sayan and the Altay, and in that part of the Yukon basin in Canada where permafrost occurs in "islands" [4, 7].

Of considerable scientific, and of some practical interest seems to be the little if at all known phenomenon of cryogenic concentration of hydrogenetic elements and compounds in some permafrost regions. It was first noted as early as the end of the last century, by L. A. Yachevskiy, south of Lake Baykal, and very briefly described by him as "An Example of Gypsum Deposition Through the Agency of Ice" [15].

Gypsum crystals covered the surface of soil and alluvial deposits, where a small "taryn" (Yakutian for frozen seepages of ground water) in the upper course of Ubur-Khubut stream, elevation about 2000 m, had first melted toward the beginning of September. Yachevskiy also noticed light-gray powder of calcium carbonate and gypsum on the surface of a partly thawed-out "taryn" in the Kharazhelga Creek valley, on the south slope of the Tunkin Alps.

Similar powdery deposits of salts on the surface of glacial sheets associated with a source of ground water were discovered in 1935, by I. Ya. Baranovich, in the Transbaykal region. A sediment of carbonate salts, locally known as "gudzhir", is formed on the taryn surface when the latter originates out of highly mineralized waters [1]. Studies of giant taryns in the Selennyakh hollow and the Tas-Khayakhtakh, in northeastern Yakutia [10], have established that powdery "gudzhirs" appear in the spring and summer on such ice fields as have been formed from very slightly mineralized ground water. For example, "gudzhirs" 10 to 12 mm in size were formed at the surface of the slowly melting Kyrsk taryn (Figure 1), although the content of solids dissolved in ground water feeding this taryn is not over 0.25 gm/liter. Chemical composition of white powder from this taryn in the beginning of the summer corresponded to the cation and anion composition in the spring water. A similar relationship was established in 1939 for spring water and for "gudzhir" from the Khodoropsk taryn fed by this water, at the Tas-Khayakhtakh Range pass. These statements are corroborated by data of Table 1.

It turned out that the chemical composition of salts dissolved in waters of taryn springs, despite their low concentration, fully corresponded to the petrographic composition of rocks and to the entire geologic make-up of the two areas. The Kyrsk spring is located at the foot of the northeastern slope of the Tas-Khayakhtakh Range, predominantly of Ordovician limestones, while the Khodoropsk spring is located at a pass over that range, with outcrops of Devonian carbonate-sulfate rocks (gypsiferous limestone). The low mineralization of these waters indicates their shallow origin and association with karst cavities in Paleozoic formations. This is corroborated by the composition of gases liberated from the Kyrsk waters.

[1]Kriogennyye geokhimicheskiye polya na territorii mnogoletney kriolitozony.

FIGURE 1. Kyrsk taryn

The correspondence of the chemical compo-
sition of "gudzhirs" formed on taryns of the Kolyma basin with petrographic conditions was established by the authors of a communication "On the Nature of 'Blooms' on Ice of the Kolyma-Indigirka Region" [3]. In an area of hot springs, "gudzhir" of two taryns consists chiefly of SiO_2, which fully corresponds to the high silica content in waters of the "Talaya" hot springs and to the absence of carbonate rocks in that area of the Okhotsk-Kolyma mountain country. An abundance of fragments and whole diatom tests in that "gudzhir" made it possible for A. K. Boldyrev, A. P. Vasil'kovskiy, and T. A. Yefimova [3] to assign it to organic formations. As a matter of fact, diatomite and other organic forms similar to coccoliths are secondary formations at the surface of taryns carrying "gudzhir". This subject was discussed before, in detail [13].

As established in 1939, the salt content in ice of the Kyrsk taryn is almost twice that of the ground water which feeds it. Moveover, the basic cation-anion ratio in the ice is the reverse of what it is in the water. This is corroborated by the following formulas for chemical composition:

$$\text{for water - M } 0.25\,\frac{HCO^3 77\ SO^4 20}{Ca\ 53\ Mg\ 56}$$

$$\text{and for ice - M } 0.44\,\frac{SO^4\ 48\ HCO^3\ 43}{Mg\ 36\ Ca\ 32\ (Na + K)\ 16}$$

The alkali content in ice is 45 times greater

Table 1

Chemical composition of waters from the Kyrsk and Khodoropsk springs and of salts deposited at the surface of taryns associated with them.

Spring	Chemical composition:	
	Spring waters (in equivalent percent)	Salts deposited on the ice surfaces of taryns (by weight percent)
Kyrsk	$M\,0{,}25\,\frac{HCO^3 76 SO^4 20}{Ca52Mg46}\,T^o 0{,}5$	$CaCO_3$ —95,23 $MgCO_3$— 1,57 $CaSO_4 \cdot 2H_2O$— 0,74
Khodoropsk	$M\,0{,}22\,\frac{HCO^3 54 SO^4 44}{Ca70Mg28}\,T^o 1{,}8$	$CaSO_4 \cdot 2H_2O$— 61,70 $CaCO_3$—39,63 $MgCO_3$— 1,54

than in water, and the chlorine content, 4.5 times. In addition, manganese is present in the ice, along with an apparently higher concentration of rarer elements.

At first, this phenomenon was explained by evaporation of ground water regularly pouring out to the surface and not freezing up immediately, even in heavy frosts. In winter, at temperatures of 50 to 55°C, below zero, a thick fog hangs over taryn areas covered with water; everything around is covered by thick hoarfrost and extremely fine crystals of newly fallen snow. The abundant local snowfalls are the result of intensive evaporation of newly surfaced waters.

Subsequently, it has also been established that carbonates, sulfates, and silicates dissolved in waters of taryn springs precipitate even before these waters come to the surface and freeze up, when comparatively warm and particularly hot flows contact a low-temperature medium (such as a flow of cold ground water) and cool off rapidly. Precipitated first are SiO_2 and $CaCO_3$, followed by $CaSO_4$ and other salts of intermediate solubility. The finest crystals of these compounds, now in cold water, pass on to the ice sheet. In water samples collected for analysis, such crystals settle at the bottom of the beaker and are not accounted for in the total soluble material.

This explanation is in fair correspondence with the facts. According to our observations, water of many taryn springs is opalescent, especially that of the Oyërgordakh and Kuydusun springs. Water from the first has a higher radium content [10].

Melting waters of a taryn flow slowly in thin films and rivulets, into depressions, while salt crystals located between the ice crystal faces and within the crystals are left behind, forming layers of powdery "gudzhir". Thus salts are accumulated, year after year; some of them are carried into soil and the seasonal thawing-out layer, which they saturate with lime and other compounds essential for cereal plants.

In 1946, I happened to visit the junction of the Indigirka and its tributary, the Moma. I noticed that taryns are responsible for stretches of excellent meadows among expanses of moss and acid peat-gley soil. This is true even when ground water which feeds a taryn is almost pure.

Located near Sobolokh village of the "Put' Lenina" kolkhoz, is a taryn with an area of about 10 km^2, mentioned by geobotanist V. A. Sheludyakova (1938). According to that author, it is produced by a small stream, barely visible in the summer and is marked by grass and sedge meadows making the best hay of the area, with a yield of up to 40 centners each hectare.

The Taryn-Yuryakh (taryn creek) mentioned by V. A. Sheludyakova originates in a vigorously bubbling spring located on the second marshy terrace of the Moma River, at the foot of the third terrace escarpment, 25 to 30 m high. The Taryn Yuryakh has no valley and no watershed above the spring. The total principal dissolved material in the spring water did not exceed 75 mg/liter.

Thus the areas occupied by giant taryns must be regarded as cryogenic geochemical fields. The fairly high concentration of hydrogenetic elements, including rare elements, takes place in the taryn itself as it is formed from ground water; as well as on the surface of ice and soil, as a result of the melting of the taryn; and in soil below the taryn and about it. The first two concentration stages are periodic, occurring year after year and producing a peculiar surface cryogenic ore. The many ores of this origin in the northwestern part of this country are yet to be studied; some of them may be workable.

The number of such giant taryns in the northwest is counted literally in the hundreds. Their individual areas are usually over 1 km^2, most often 2-5 km^2, locally 5 to 10 km^2, and occasionally 10 to 30 km^2. The largest known in the world, the Ulakhan Taryn, is located in the Moma valley, not far from the crater of a young volcano; its area is over 100 km^2 with a volume of over 250 million m^3. Average size taryns which we have studied contain, as a rule, over 5 million m^3 ice. These ice fields, which we have named hydroextrusives, are over 2 m thick, as a rule (see Figure 2); quite commonly 5 to 7 m [10].

The immediate and urgent task is a comprehensive study of "gudzhirs" on these taryns, as well as ice-free springs in the upper Moma course, located near large granite massifs, with young and rejuvenated faults passing in the same vicinity.

We shall now turn to a very brief consideration of another kind of cryogenic geochemical field with which we are familiar and which is related to the upward migration of materials dissolved in ground water in a periodic freezing of the surface layer. Such a geochemical field was discovered in 1935, in the Melkiy Creek floodplain, not far from the Melko-Anadyrsk estuary [9, 11].

Powdery loams drilled below 1.5 m and to the total depth in this area, remained unfrozen throughout the year, although their temperature was 3°C, below zero, getting down to 6 or 9°C.

This "liquid frost" turned out to be a brine with a dissolved mineral content of over 100 gm/liter; i.e., three times more than in sea water and at least five times more than in the

FIGURE 2. Thick ice covers (hydro-extrusives).

Anadyrka estuary, at high tide. An incomplete chemical analysis of this brine has revealed a ratio of components about the same as in sea water [11].

The considerable increase in the amount of calcium and hydrocarbonate ions, compared with sea water, must be regarded as a result of exchange reaction with colloid suspensions in river water when it commingles with sea water, as well as with clay fractions of continental deposits on the low shore of the Melkaya cove, where estuarine waters infiltrate these deposits.

This great increase in the concentration in ground water solutions of estuarine origin (5 to 6 times higher) on the flood plain inundated by the Melkaya cove waters is probably not due to surface water evaporation alone. The fact is that the Anadyrka estuary coast is a typical area of excess humidity, with the amount of summer precipitation definitely exceeding evaporation. To explain the rising salinity of ground water, we will have to postulate a migration of ground moisture in clayey and phytogenic formations, toward the periodically frozen soil and within it, as an effect of temperature and moisture content gradient or, in other words, in the presence of a capillary potential [5, 6]. An enrichment of the upper and hardest frozen horizon in ice intercalations, in the freezing of water "drawn-up" from below, means a rise in the ground solution concentration at lower horizons, i. e., a salting up.

In a rapid thawing of the uppermost ice-enriched layer, almost all of its water flows to the creek and on to the estuary. A downward movement of the thaw water is dammed by a shallow layer of low-temperature frozen loam, virtually impermeable. These phenomena, reoccurring year after year, lead to the formation of typical salines in subarctic areas of excess humidity. The periodic freezing of topsoil is geochemically equivalent to its drying up observed in arid areas of middle and low latitudes.

In conclusion, we express the hope that cryogenic processes and factors will soon be assigned their proper place among others affecting dispersion and mineralization haloes and the concentration of chemical elements in the crust and on its surface. The need for considering these factors in analyzing the formation conditions of Anthropogene mineral deposits has already been presented to the geologists and paleogeographers (see 6, p. 420).

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TRACKS OF A CREEPING ANIMAL AT THE BOTTOM OF THE PACIFIC[1]

by

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Observations of the life activity of present-day marine animals are of great importance in explaining the mystery of some formations often occurring in rocks. Foremost among those are the assorted hieroglyphs and fucoid patterns observed in thick flysch sections generally poor in organic remains.

Some of these hieroglyphs are of inorganic origin, associated with the mechanical action of water, the winnowing of bottom sediments, etc. (mechanoglyphs). Other hieroglyphs, as correlated with present-day patterns, turned out to be tracks (or their casts) of worms, gastropods, and other animals (bioglyphs). The fucoids, formerly supposed to be algal remains, turned out to be traces of worm activity.

It has been established by a comparison with present-day burrows of higher crustaceans that the peculiar sandy rod-shaped to dendritic concretions present in many formations are burrow fillings of Callianassa, etc. [9]. Various formations described as Octovorallia turned out to be traces of bottom animals [10]. An imprint described as that of a sitting pterodactyl was subsequently correctly interpreted as a xiphozur track ([7], p. 146). A number of other riddles have been more or less explained.

Recently a special branch of paleoecology has been developing, a study of fossil tracks, known as paleoichnology. Much work in this field has been done by O. Abel, R. Richter, W. Häntzschel, A. Seilacher, G. Roger, J. Lessertisseur, and other students.

Deciphering fossil tracks by their correlation with present-day types is difficult for two reasons. First of all, observations of present-day traces of animal activity are made ordinarily in a directly accessible littoral zone, at low tide, and partly on the beach, i. e., in a very limited belt. Moreover, such observations are few because biologists are more interested in the animals themselves than in their tracks, while paleontologists only rarely have the opportunity for a special study of present-day tracks. A broadening of the field of observation is possible through diving and submarine photography, which is an extremely important means of studying the sea bottom beyond the littoral zone and down to great depths. However, catching the animal itself in the process of making its bottom tracks is too much to hope for. And so, in attempting to decipher such tracks, we find ourselves in the predicament of a paleoichnologist who sees the tracks but not its makers.

One purpose of this paper is to draw the attention of biologists and paleontologists to present-day tracks. Gathering the data and publishing the descriptions, sketches, and photographs of such tracks will be helpful not only in fossil identification but in solving many present-day problems, provided the relationship between an animal and its track can be established.

In our particular study, we were unable to arrive at any definite conclusion. Still, the track itself and the fact of its preservation at a great depth are so interesting that we have decided to publish its photograph along with some thoughts on its possible origin.

Submarine photography has long been used on board the "Vityaz", an expedition ship of the Oceanology Institute, Academy of Sciences, U. S. S. R. The first photographs were taken at shallow depths down to 100 m, as early as 1953 [3]. With improved equipment, it has become possible to take whole series of bottom pictures at practically any depths [3, 4, 5].

One of the photographs showed a very interesting sinuous track (Figure 1) which is the subject of this communication. This photograph was taken in 1957, in the western Pacific, between the Carolinas and New Guinea (1° 30' N l., 154° 07' E l.) at 2970 m. Bottom samples revealed globigerina ooze.

[1]Sled polzayushchego zhivotnogo na dne tikhogo okeana.

FIGURE 1. Track Mystichnis pacificus gen. et sp. n., from the bottom of the Pacific; depth, 2970 m.

The light source was to the right of the photograph. From the disposition of the shadows, we conclude that this track is convex. It is about 10 cm wide, with a well-defined groove in the middle of it. Located on either side of this longitudinal groove are straight transverse swells alternating with grooves. Inside ends of transverse swells fall opposite those on the other side of the longitudinal groove or somewhat offset, with a swell in one row falling opposite a groove in the other. All these swells and grooves are of the same type, although somewhat different in width; with the length about 4.5 cm, the swells are 0.7 to 1.6 cm wide and the grooves are 0.7 to 0.9 cm wide; the swells stand about one centimeter high above the bottom of the grooves. It is of interest that the width of the swells is cut almost in half at sharp turns of the track, while the grooves remain almost unchanged.

This main track is crossed in its middle part by another, representing a very narrow sinuous groove, apparently flat but with barely perceptible lateral swells. The photograph also shows a number of minute, smooth, bent tubes, perhaps evidence of warm life activity. Judging from their shadows, these are swells rather than grooves.

Thus the main track is double, consisting of a narrow median groove and wide lateral zones of alternating swells and grooves. We can tell immediately that it was made by a moving animal, evidently a crawling one.

In typing to decipher this track we are forced to turn, as in paleoichnology, to observation data on present-day animals on a slimy bottom, also to some considerations of the mode of locomotion of various animals.

The transverse grooves and swells could not have been made by a smooth body in sliding motion. Obviously, these are traces of some limbs or lateral growths (parapods of worms, limbs of arthropods, fins of fishes) or else traces of the undulating movement of a soft crawling body (such as a gastropod foot).

It should be noted that tracks very similar to ours were photographed twice by the Englishman A. S. Laughton [11, 12] in the Atlantic, at depths of 4685 and 5285 m (Figure 2). These tracks, too, have a longitudinal median groove and wide zones of transverse swells and grooves; their size is about the same as our tracks. Unfortunately, photographs of the Atlantic tracks are not sharp enough for a detailed analysis. A. Laughton ascribes them either to holothurians or to crustaceans.

Let us consider all possible origins of these tracks. The groove could have been made by the ventral part of a bottom-hugging fish. As this is rather unlikely, such a groove could have been made by the anal fin or the tail. The transverse grooves could have been formed in the movement of ventral fins; this presupposes a very fast and quite uniform movement, for at least two meters (visible length of track). The anal fin or tail must have been stationary because the median groove maintains the same width and does not become less sharp, as if washed out, even in the fairly sharp turn of the track calling for a considerable bend in the body. This turn in itself, quite sharp although even, is hardly probable for a fairly large smoothly swimming fish. A bottom fish would have a broken track, as it alternately touched the bottom and rose above it. For these reasons we doubt that this is a fish track.

Among other deep-water bottom organisms with lateral growths are holothurians of family Elphididae [1, 6]. However, they are rather small (up to 5 cm long), with ventral ambulacres extending from their periphery. Their progress would have been marked by a much broader smooth median groove; moreover, the lateral appendages would have left á number of different grooves, rather than a uniform pattern. In addition, these animals are extremely sluggish, not likely to have made such a long track.

A double track with lateral grooves can be made by gastropods having a ditaxic locomotion, according to the Vlés classification [17]. We see this, for instance, in the Monodonta lineata Da Costa track illustrated by J. Lessertisseur ([13], Figure 10-B in text; Plate II, Figure 2). In that instance, however, the grooves and swells are not normal to the median groove but at a sharp angle. J. Lessértisseur compares the Monodonta track to that of Phyllodocites saportai Delgado, from the Silurian of Portugal, indeed quite similar to it ([13], Plate VI, Figure 8). It is to be noted that the transverse grooves on one side of that track are oblique to the median groove, while almost normal to it on the other side. In addition, that track, unlike ours, is bound on either side by narrow grooves parallel to the median and not always visible; the track is only 6 mm wide.

Another similar fossil track attributed to gastropods is Isopodichnus tugiensis Speck from Pre-Alpine Miocene molasse ([14], Figure 2, Nos, 4, 15).

On the basis of his observations along the South African coast, O Abel described and illustrated a series of creeping Bullia tracks (family Nassidae), with a diversified sculpture, depending mostly on the moisture content of the ground. This mollusk inhabits the tidal zone. The sole of its foot is quite conspicuous in size, greatly enlarged in creeping, and is almost 2.5 times broader than the shell itself ([8], Figure 196). The last whorl of the shell

FIGURE 2. Track photographed by A. Laughton at the Atlantic bottom, 5285 m.

in an adult specimen is about 1.8 cm wide, while the maximum width of its track is 5 cm ([8], Figure 217). It must be emphasized that almost all pictures of the Bullia tracks show quite clearly the marginal grooves made by the two lateral edges of the foot, as well as lateral swells (either smooth or with a beady sculpture) formed by the ground pushed away by the front edge of the foot, in motion.

This linear outline is missing in our track where the lateral edge has a zig-zag pattern because of the protruding transverse swells. None of Abel's illustrations is similar to ours; we mention them only to show that gastropods can make tracks with a transverse pattern, different in tracks of the same species of genus Bullia; and that a great width of the track does not necessarily mean a wide shell. Gastropod tracks, besides being strictly surface features, may occur in interior "galleries". Finally, on the basis of his observations, O. Abel offered a new interpretation for fossil formations long known from the Eocene flysch at Kirling (Vienna woods): He regarded them as tracks of Eocene Bullia (Palaeobullia). What is more, O. Abel has applied his conclusions to many other fossil tracks (from the Paleozoic on), in maintaining that the so-called Nereites, Nemertites, Myrianites, Phyllochorda, and many other forms similar to them, also represent creeping tracks of gastropods. Such tracks (or their casts) were first described as "fossil snakes" [16]. Later on they were regarded as fossil annelids, similar to Nereis (whence the name Nereites); then as imprints, and finally as tracks of creeping annelids.

A special mention should be made of giant Climactichnites, straight to slightly bent tracks, up to 12.5 cm wide and up to 4.5 m long, from Upper Cambrian deposits of North America [8]. They show a median groove and lateral bands with transverse straight but slightly oblique swells and grooves, in a herring-bone pattern. All tracks are hemmed by a well-defined groove. They all begin with an elongated oval smoothed field thought to be the imprint of the animal body prior to motion. O. Abel believes that Climactichnites, too, is a creeping track of littoral gastropods washed on to the beach by waves; he assumes the existence of a shell-free Opistobranchia group, as early as the Cambrian [8].

It should be noted that Abel's interpretation of fossil tracks with a double and triple transverse pattern, as gastropod tracks has gained wide recognition.

Returning to our track, we must note that, in pattern it is reminiscent of some fossil tracks attributed to gastropods. The main difference is in the disposition of transverse swells, normal rather than oblique to the central groove, and in the absence of an even

lateral outline in the shape of a marginal groove or a marginal swell.

So far as we know, large gastropods with a foot diameter up to 10 cm are unknown as yet from great depths. For this reason, while not categorically rejecting such an explanation, we doubt that our track has been made by a gastropod.

Moving arthropoda, besides leaving disjoined traces of individual limbs, can make "unbroken" tracks similar to ours. Similar tracks, in galleries up to 3.5 cm wide, raising the surface layer of sediments, are present in Platyonychus latipes Penn (13, Plate III, Figures 10-11, and Figure 16-c in text). There is one more type of Carcinus moena Peron tracks with a transverse pattern, described by J. Lessertisseur [13].

We believe that in morphologic features our track is similar to those of some arthropods.

Worm tracks are mostly smooth and uniform. As such, they are most common as fossils (vermiglyphs). On the other hand, the formation of lateral grooves (and of swells separating them) is quite probable in fine ooze, as traces of moving parapoda, as demonstrated by the Nychia cirrosa track ([13], Figure 6-c in text). For this reason, the possibility of this being a worm track (Polychaeta) cannot be rejected out of hand.

This concludes our consideration of present-day animal tracks, because we do not know of any other animal groups with tracks comparable with those illustrated in our photograph.

This discussion, of necessity short because of the small number of available published descriptions of other tracks, leads to the following conclusions.

Morphologically similar tracks can be made by Gastropoda, Polychaeta, and Arthropoda (Decapoda). We have no reasons to prefer one group over the others.

The absence of a uniform marginal groove and swell, together with the normal position of transverse grooves and swells with reference to the median groove militates against this being a gastropod track. Furthermore, we do not know of any such large deep-water gastropods).

As to Polychaeta, it is doubtful that parapods could have been responsible for such a pronounced feature of deep transverse grooves. Again, we do not know of any such large Polychaeta. However, abyssal population is so little known that many and quite unexpected facts may come to light, in the future.

This may be the track of a member of the arthropod group, the Decapoda which inhabit quite considerable depths and attain a large size.

Tracks similar to ours are known to exist. Included are those described and known as Phyllochorda Heer, 1864; they are cited by J. Lessertisseur as a type of triple tracks ([13], Plate V, Figure 9; and Figure 2-d in text).

Similar fossils have also been descibed under different names (Crossopodia McCoy, Nemertilites Meneghini, etc.). They are known from the Silurian on. Their origin is unknown, but attributed mostly to worms and gastropods.

Special mention should be made of a track from Jamna (Paleocene) sandstone in the Prut basin of the Carpathians, as illustrated by R. Zuber (Figure 3). Besides the Climactichnites, this is the only track known to us which is large enough to be comparable to ours [18]. It is up to 8.5 cm wide; the preserved segment is 20.5 cm long. The specimen is stored in the Geology Department Museum of Lvov University. This appears to be the case of an impressed track with a very narrow median groove and sickle-like lateral swells, widely spaced and approximately as wide as the grooves separating them. Its origin is obscure.

It appears from this brief description and from a comparison of the photographs that the Pacific track is quite different from the Carpathian one, in the rectilinear and close pattern of its lateral swells. However, neither a marginal groove nor a swell is present in either track.

We have already mentioned that our predicament is the same as that of the paleoichnologist studying fossil tracks. It would be incorrect to leave without any name all the diverse fossil riddles, evidence of life activity, and to confine oneself to a general description alone. It is necessary to classify such tracks.

Being unable to determine definitely the systematic position of the animal whose trace it is (a higher taxonomic unit, let alone genus and species), paleontologists resort to an artificial classification. We deem it expedient to assign special names even to those present-day tracks which cannot be associated with any specific animal and which, too, are riddles. The question arises, is it proper to assign to modern tracks the names already assigned to similar fossil tracks? Perhaps our track, too, should be designated as Phyllochorda (or else Crossopodia, Nemertilites, etc.). The considerable confusion in the nomenclature of fossil tracks, and our intention to discriminate in some way between the two groups, have moved us to suggest special names for present-day

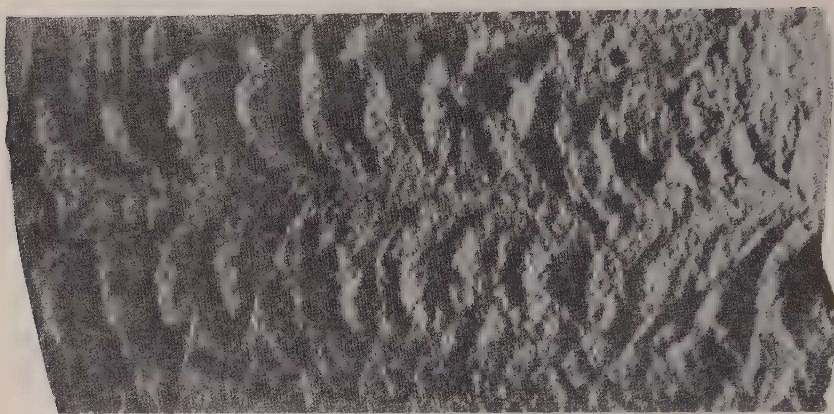

FIGURE 3. Hieroglyph (creeping track) from the Jamna series in the Carpathian flysch (Paleocene).

Village of Jamna on Prut River, Eastern Carpathians (After R. Zuber, [18], p. 116, Figure 76). 1/2 actual size.

tracks. Obviously, more and more new tracks will be discovered by means of submarine photography, and they will call for artificial systematics. There always is the hope that with luck, the animal itself will occasionally be photographed with its track.

For all these reasons, we propose to name this track Mystichnis pacificus gen. et sp. n., with the following brief description of this artificial genus and species.

Mystichnis pacificus gen. n.: a double, irregularly bent creeping track with a narrow median groove and broad transversely-grooved lateral bands.

Mystichnis pacificus sp. n. is an extremely large track (as much as 10 cm wide); lateral grooves and swells are close together, rectilinear, normal to the median groove.

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STRUCTURE OF THE PRECAMBRIAN BASEMENT IN THE NORTHERN PART OF THE RUSSIAN PLATFORM[1]

by

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Present in the folded basement in the northern part of the Russian platform is the Baykalian fold system (in its outer northeastern corner) and the vast Karelian fold system continued in the structure of the eastern Baltic shield and including large Archean massifs. Regional geophysical data, correlated with drilling data, differentiate in more detail the basement surface of the eastern slope of the Baltic shield, Moscow syneclise, the northern part of the Volga-Ural anteclise, Timan, and the Pechora syneclise, and in addition some new structural elements.

* * * * *

The problem of the age and structure of platform basements is quite important inasmuch as its solution permits a better understanding of the tectonic development of the platform sedimentary mantle.

This paper purports to consider the main features in the structure of the Precambrian basement in the northern part of the Russian platform. A number of publications deal with this subject.

Of great interest among earlier works is a tectonic scheme of the Russian platform compiled in 1937 by A. D. Arkhàngel'skiy [1] who was the first to use magnetic and gravity data in his analysis of the internal basement structure.

In 1946, N. S. Shatskiy [32] published a new tectonic map of the Russian platform, based on a thorough analysis of the geology of its shields and on a study of the map of magnetic anomalies. He identified within the platform periods of Archean, Karelian, and Baykalian folding. The general features of his map have been verified by subsequent geologic and geophysical data. In 1947, E. E. Fotiadi [24] compiled the first contour map on the basement of the entire Russian platform, from drilling and geophysical data.

In the following years, several new structural maps of the basement of the Russian platform have been published in connection with the planned development of control and deep exploration drilling. For the area in question, the basement was represented on maps by A. A. Bakirov (1951-1954), M. M. Tolstikhina (1951), V. D. Nalivkin assisted by a group of authors (1952-1956), E. E. Fotiadi (1950-1957), Ye. M. Lyutkevich (1951), and a number of others. The platform basement structure has also been represented on the "Tectonic Map of the U. S. S. R." (1953 and 1956 editions) compiled under the direction of N. S. Shatskiy.

Important information on the basement structure of the northern part of the Russian platform was obtained in 1954-1957, as a result of the regional aeromagnetic survey within it (as far as the Baltic shield in the west), carried out by the Siberian Geophysical Trust. The original data of this survey were processed and interpreted by the present writer (1955-1957). In the following years, these data were extensively used and interpreted by E. E. Fotiadi [24] in compiling new tectonic maps of the Russian platform, the best maps reflecting the structure of its basement. In addition, aeromagnetic data, along with gravity and drilling data, were used in a number of tectonic maps of the northeastern part of the Russian platform, by M. V. Kas'yanov (1955), O. A. Kalinina (1954-1959), V. A. Levchenko (1954-1957), and V. S. Zhuravlev and the writer (1959).

In recent years, the Kola Peninsula and Karelia were covered by ΔT aeromagnetic surveying (Western Geophysical Trust, 1957-1959); after that, it became possible to extrapolate with more certainty the data on the structure of the Baltic shield, to the buried part of the platform.

The basement tectonics presents two fundamental problems [12]: a study of the internal

[1]Stroyeniye dokembriyskogo fundamenta severa Russkoy platformy.

structure and a study of the basement surface, or its relief, which determines to a large extent the structure and thickness of the platform mantle. These two problems are closely related and their joint analysis is necessary for a correct solution of the problem of the basement tectonics, as a whole.

I. THE STRUCTURE AND COMPOSITION OF THE PRECAMBRIAN IN THE EASTERN PART OF THE BALTIC SHIELD AND TIMAN

In this part of the platform, the folded basement is exposed in the eastern part of the Baltic shield (Karelia and the Kola Peninsula), as well as in Timan and the Kanin Peninsula. Over the rest of the vast expanse in the north and northeast, the platform basement is under a mantle of platform formations and may be reached by drilling only in isolated areas. The basement structure in exposed areas (Baltic shield, Kanin Peninsula, Timan) has been studied directly by a number of authors [8, 13, 19, 21, 23, 25, 26, 28].

The eastern part of the Baltic shield is formed by Karelian fold structures. They present a system of synclinoria with a general northwesterly trend, are filled with thick volcanic-sedimentary Karelian formations, and separated by uplifts in Archean rocks. These uplifts are manifested as large anticlinoria or large interior massifs [13, 19, 26, 32].

South of Kandalaksha Bay and Onega inlet, there lies the immense Belomorsk massif (Figure 1) of Lower Archean paragneisses and basic extrusives, highly disturbed, thoroughly metamorphosed, and granitized in pre-Proterozoic time [26]. The trend of folding of these most ancient formations is chiefly to the northwest, locally complicated by northeasterly trending folds. In the southwest, the Belomorsk massif is bound by a complex Karelian fold zone; and in the northeast by the Kola fold zone [26, 32]. They differ from the Belomorsk massif in their extensive development of Proterozoic formations and are divided into a number of major anticlinoria and synclinoria. Exposed in anticlinorial cores are Archean gneisses structurally reworked and intensively granitized during Karelian folding.

Proterozoic formations in synclinoria of the Karelian and Kola zones are divisible into two series [26]. The lower is made up of early Karelian iron-ore, spilite keratophyre, and schist formations, intensively folded and intruded by basic crystallines and granite, strongly metamorphosed, and granitized in pre-Proterozoic time [26]. The folding of these early karelids is linear with a predominantly northwestern trend.

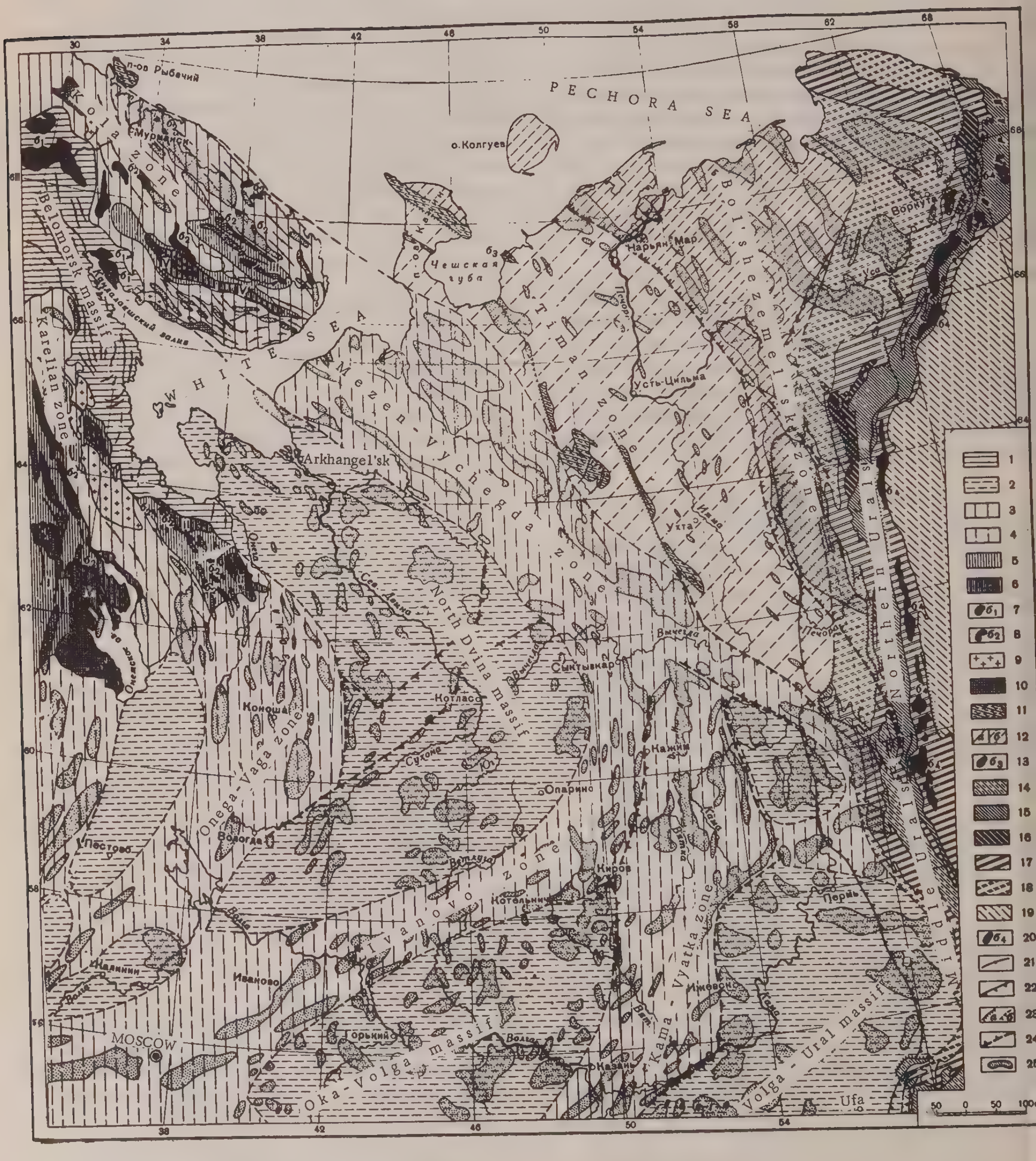
Upper Proterozoic rocks, or later karelids [26], are represented by volcanic and sedimentary complexes, intensively folded in the middle and at the end of late Proterozoic. Their trend is generally northwest.

Younger formations of the Precambrian basement are exposed along the northeastern margin of the Baltic shield, on the Varanger and Sredniy Rybachiy peninsula, and in Kildin Island. They are represented by thick terrigenous Riphean rocks [32], widely known as the Hyperborean, Sparagmite, and Eocambrian formations [26, 27, 32]. This zone is traceable far to the southeast, within the northeastern margin of the Russian platform (Kanin Peninsula and Timan), where they form a single folded system which originated, according to N. S. Shatskiy [30, 32], during the Baykal (Riphean) folding. In the Kanin Peninsula and Timan, Riphean folded metamorphics are exposed in the cores of the largest uplifts. Their stratigraphy and tectonics are described by a number of authors [8, 14, 21, 23, 28] who identify several formations (with a total thickness of over 7000 m), probably separated by angular unconformities. The lower Chetlas formation [8, 23] is represented by assorted, largely quartz-sericite schists. It is overlain by quartzitic sandstone and schist of the Dzhezhim and Bobrovsk formations [8, 23]. The section terminates in algal dolomite and whetstome schist of the Bystrukhino formation [23]. In the Kanin Peninsula and north Timan, metamorphic schists are cut by numerous intrusions of gabbro, granite, and syenite [28, 29]. Orthoamphibolite sills are involved in the folding, along with the schist. In south Timan, in the Ukhta area, granite, syenite, and quartz monzonite are exposed in the folded basement, along Verkhnyaya Chut River and in areas of villages Nizhnyaya Omra and Izkos-Gora [21].

As noted by many students [5, 10, 29, 31], Riphean formations in Timan are quite similar to those of the Polyudov Kamen and Baskhirian uplift, on the west Uralian slope. The Chetlas schist of Timan are correlative with the Yurmatinsk and Burzyansk schists of the Bashkirian uplift [10], while the Karatavsk series in the uplift, as well as the Rassol'ninsk, Deminsk, and Niz'vensk formations of Polyudov Kamen, are probably correlative with the Dzhezhim, Bobrovsk, and Bystrukhino formations of Timan [10]. At the same time, the Kanin Peninsula and Timan metamorphics differ in composition and metamorphism from the Riphean formation of the Arctic Urals, although similar to them in thickness. The Riphean section of the Arctic Urals is now subdivided into four series separated by stratigraphic and angular unconformities [20]. The Khadatinsk series, the lowest, is represented by strongly metamorphosed rocks, mostly amphibolite and gneiss. They are overlain by the Shchuchin and Verknesobsk series [20] of quartzite, chlorite schist, and marble. The fourth and

the youngest Riphean series, named the Pendirma-pe by M. Ye. Raaben [20], is developed on the western slope and in the south of the Arctic Urals, where it is exposed in anticlinal cores. This series is represented largely by volcanic rocks, over 2000 m thick.

The nature of these Riphean formations definitely suggests their deposition in the interior of a Riphean geosynclinal province [32]. Unlike them, Riphean sequences in Rybachiy, Sredniy, and Kanin peninsulas, Kildin Island, Timan, Polyudov Kamen, and the Bashkirian uplift, were formed in the outer zone of the same geosynclinal province. It must be emphasized that the Riphean of the outer zone, in the nature of its formations, degree of deformation, metamorphism, thickness, and intrusive phenomena, is quite different from that of central and eastern regions of the Russian platform where it is the base of the sedimentary mantle section [10, 34].



II. INTERNAL STRUCTURE OF THE PRECAMBRIAN BASEMENT IN THE NORTHERN PART OF THE RUSSIAN PLATFORM

The lack of homogeneity in the structure and physical composition of the folded basement in the northern part of the platform is reflected in the nature of structural features of magnetic and gravity anomalies which form relatively regular regional zones (Figure 1). It has been established fairly definitely by now that the gravity anomalies are controlled on the whole by the total effect of irregularities in both the basement and mantle, while magnetic anomalies reflect the structure and physical composition of the basement alone, because the mantle rocks are paractically non-magnetic, as a rule. Outlines of magnetic rock massifs in the basement, responsible for these anomalies, are determined with a fair degree of certainty [14] from inflection points (Figure 1).

The magnetic field of the northern Russian platform, southwest of Timan, is characterized in the most general way by a development of vast provinces with a mosaic of anomalies separated and girdled by zones of linear maxima correlative with anomaly systems of the Baltic shield.

At the same time, Timan and the Pechora syneclise are marked by a different structure of magnetic fields, being affected by a regional Timan minimum and by banded anomalies of the Bol'shezemel'sk zone which form a general northwesterly trending system. The presence of differently oriented magnetic anomaly zones within the platform, differing also in morphology and intensity, has been regarded by most students [1, 32] as sufficient reason for dividing the basement into a number of noncontemporaneous complexes of Precambrian folding. Provinces with a mosaic arrangement of the magnetic field have been regarded as ancient massifs, while the systems of banded anomalies about them have been taken for an adjustment of younger folding to the outlines of ancient massifs and blocks. Similar structural relations are quite distinct in the Baltic shield [13, 19, 26, 27, 32]. These important peculiarities in the Archean and Karelian folding in the Baltic shield are properly reflected in the structure of the regional magnetic field.

The Karelian zone of Proterozoic structures in the Baltic shield is characterized by a banded magnetic field closely related to the structure and composition of rocks filling up its synclinoria and anticlinoria. Its component East Karelian, Onega, Segozero, and West Karelian synclinoria [13] are made up of thick spilite keratophyres and ferruginous schists which are strongly magnetic and are reflected in intensive linear anomalies. Chains of numerous ultrabasic and basic intrusions within them are marked by narrow magnetic anomalies in elongated systems.

The Belomorsk massif of the Baltic shield, formed by very tough and non-magnetic ancient Archean gneisses, is marked by an evenly depressed field only locally disturbed by changes and rises; this suggests a poor development of magnetic rocks.

The Kola zone of the Baltic shield karelids is marked by a complex, anomalous magnetic field, due to the numerous magnetic intrusive and extrusive formations. Its component Pechenga-Varzuta synclinorium [26] of

FIGURE 1. Tectonic map of the Precambrian basement in the northern part of the Russian platform.

Karelian Fold Province

1 - Archean (intra-Karelian) massif exposed on surface; 2 - buried Archean (intra-Karelian) massifs; 3 - exposed Karelian folded zones; 4 - buried Karelian fold zones; 5 - West Karelian, East Karelian, and Kola-Keyv synclinoria of Proterozoic gneiss and schist; 6 - Onega and Pechenga-Varzuta synclinoria, mostly of Upper Proterozoic volcanics; 7 - upper Archean basic to ultrabasic intrusions; 8 - Proterozoic basic to ultrabasic intrusions; 9 - Proterozoic granitoids; 10 - Jotnian formations of the Baltic shield.

Baykalian Fold Province

11 - outcrops of Riphean folded basement in Timan, Kanin Peninsula, and in the northeastern margin of the Baltic shield; 12 - Baykalian fold province underneath sedimentary mentle: a - outer (miogeosynclinal) zone; b - inner (eugeosynclinal) zone; 13 - Riphean basic and ultrabasic intrusions in Timan.

Hercinian Fold Province

14 - zone of Riphean miogeosynclinal formations in the Urals (lower structural stage of Hercinian folding); 15 - zone of Riphean eugeosynclinal formations in the Urals (lower structural stage of Hercinian folding); 16 - zone of the thickest Riphean volcanics in the Urals; 17 - zone of the middle structural stage of Hercinian folding in the Urals ($O - C_1$); 18 - zone of the upper structural stage of Hercinian folding in the Urals (interior zone of Uralian foredeep); 19 - province of Hercinian folding underneath the sedimentary mantle; 20 - basic and ultrabasic intrusions in the Urals; 21 - general trends in fold provinces; 22 - western boundary of the Uralian foredeep; 23 - normal, reverse, and steep thrust faults; a - established; b - buried under sedimentary mantle and assumed; 24 - tectonic breaks (deep faults, regional flexures, etc.); 25 - outlines of magnetic rock massifs in the Precambrian basement (identified from inflection points in magnetic anomalies).

sedimentary volcanic rocks is marked by a strong linear anomaly in its western part, and by three nearly latitudinal banded anomalies in the eastern.

Just as sharp linear magnetic anomalies correspond to the eastern part of the central Kola anticlinorium and the Kola-Keyv synclinorium [13, 26] and are associated here with basic and ultrabasic intrusions, spilite bands, and alkalic granite, gneiss, and schist of the Keyv formation [26].

The large Murmansk anticlinorium [26], made up largely of assorted granitoids, is reflected in a heterogeneous magnetic field characterized by a development of banded anomalous zones and isolated local anomalies. Here, the areas of a depressed magnetic field correspond to microcline granite, granosyenite, and gneiss, while the maxima are associated with massifs of diorite, granodiorite, and dikes of basic and ultrabasic rocks.

A zone of thick terrigenous Riphean formations along the northern margin of the Baltic shield (Rybachiy and Sredniy peninsulas, and Kildin Island) is marked by a depressed magnetic field.

Principal magnetic zones in the Baltic shield, corresponding to the Belomorsk massif and the Karelian and Kola zones, are traceable along the same trend far to the southeast from the Precambrian outcrop boundary, thus reflecting their distant extension under the sedimentary mantle.

This buried extension of the Karelian structural zone is reflected in two bands or branches of magnetic anomalies. One of them passes between lakes Ladoga and Onega and on to the south, toward Valday and the West Dvina sources. The other zone, the east Onega-Vaga, is separated from the first by a buried Archean massif and continues southeast, to the Onega-Vaga watershed. Then it veers smoothly to the southwest, toward Kalinin, and merges farther on with a latitudinal Moscow karelid zone. The Onega-Vaga buried karelid zone, as well as the Karelian zone of the Baltic shield, is well outlines by gravity minima bands.

The elongated negative magnetic zones and the gravity maxima corresponding to the Belomorsk massif extend southeast of the Baltic shield into the North Dvina basin, thus marking the extension of the massif underneath the sedimentary mantle. Generally speaking, this vast buried massif is outlined by the North Dvina depressed magnetic province with a complex mosaic pattern (Figure 1). Rocks of this massif have been penetrated by drilling in Nenoksa, Arkhangel'skoye, and Ust-Pinega, where they are represented by Archean granite, plagiogneiss, and gabbro-amphibolite. Far t the southeast, in a marginal part of the mass Archean granitoid gneisses were penetrated b a test in the Oparino village area. Along the Sukhona, this Archean massif appears to be bound by a deep fault marked by a regional m netic minimum which is traceable on a northeasterly trend in the junction zone of meridion anomalies of the Onega-Vaga belt with northeasterly anomalies within the North Dvina ma sif. Thus, the Sukhona deep fault separates non-contemporaneous complexes of the folded basement. Traceable parallel to it in the central part of the North Dvina massif is the Kotlas-Vologda zone of pronounced gravity maxima; judging from drilling data at Pestovo they mark a belt of basic to ultrabasic intrusions in the basement [24].

The pronounced bands of magnetic maxima and minima of the Mezen-Vychegda zone, extending from the White Sea strait to upper courses of the Vychegda and Kama, are a dir southeasterly extension of the Kola linear anomalies. Thus, this entire orderly system of the Mezen-Vychegda magnetic anomalies, along with the zone of banded maxima coupled to it in the south, is probably related to the distribution of Karelian rocks.

At the latitude of Syktyvkar, this system o banded maxima broadens abruptly into a fan o southerly and southwesterly linear zones. Th westernmost are the Kirov-Syktykvar and Ivanovo zones which embrace the North Dvina massif in the south and southeast and are traceable, by way of Ivanov, to their junction with the Moscow latitudinal zone. The latter is a marginal zone of Karelian folding bounde in the south by the immense Archean Ukraine Voronezh platform block [32].

The Ivanovo linear zone separates the Nor Dvina massif from the Oka-Volga massif to th south of it, which is marked by a mosaic mag netic field. Archean rocks within it have bee penetrated by numerous test holes. In its position, the Oka-Volga massif corresponds the western part of the Oka-Ufa block identifi by A. D. Arkhangel'skiy in 1937 [1], on the basis of his interpretation of magnetic maps. A Kama-Vyatka zone, marked by a system of linear anomalies, separates the Oka-Volga massif from a major Archean Volga-Ural ma sif marked by a mosaic of magnetic and gravity anomalies. The main components of that massif, as revealed by drilling data, ar assorted gneisses and migmatites.

The presence of the Kama-Vyatka Kareli zone, suggested by aeromagnetic data, is corroborated by the drilling in lower Proterc zoic rocks along the Grakhansk-Yelabuga sw as well as in the northern part of the Tataria uplift and to the south, in the Zhiguli-Pugach uplift [3]. Its boundary with the Oka-Volga

massif is marked by the Vyatka deep fault with an associated basement belt of lower Proterozoic gabbro-norite intrusions. This fault is expressed in the sedimentary mantle structure as a system of Vyatka disturbances [15]. Another deep fault marks the boundary between the Kama-Vyatka zone and the Archean Volga-Ural massif; this fault is marked by a band of magnetic maxima and by the Grakhansk-Yelabuga surface swell [15]. This zone of Karelian rocks is traceable far to the north, along the trend of banded magnetic anomalies, in the Kama headwaters area, where it joins the Mezen-Vychegda zone.

This analysis of aeromagnetic data gives a good idea of the distribution of Karelian folding below the platform mantle throughout the northern part of the platform, as far as Timan in the northeast. It appears then that Karelian folding has played an important part in the formation of the basement of the Russian platform. By welding together the two immense ancient massifs, Svekofennian and Ukraine-Voronezh, as well as a number of smaller massifs (North Dvina, Volga-Ural, Oka-Volga, etc.), it was responsible in effect for most of the basement of the Russian platform, without its Timan outer segment, as pointed out by N. S. Shatskiy [32].

Metamorphic schists of Timan, along its entire extent, are outlined by a regional magnetic minimum which also includes the western half of the Pechora syneclise, as far as the Pechora swell in the northeast, thus indicating that the basement here, too, is made up of similar non-magnetic metamorphics.

The western boundary of the Timan folded Riphean formations, and their junction with the karelids, is marked by an abrupt replacement of the Timan regional minimum by banded anomalies of the southwestern Timan region. The entire length of this boundary is represented by a Timan-front deep fault [4] along which the east-dipping horst blocks of Timan metamorphic schists are raised high. Far to the southeast, this deep fault changes directly to the main Polyudov Kamen thrust which brings to the surface folded Riphean formations [29]. Thus, the thrusts which bound the shelves of Timan and Polyudov Kamen schists in the southwest, are but a surface expression of the deep and steep Timan-front fault which separates the provinces of typically platform Riphean sequences from the Baykalian fold provinces along their northeastern periphery in the Russian platform.

Banded magnetic anomalies developed in the eastern part of the Pechora syneclise, in the Bol'shezemel'skaya tundra, and in the Pre-Urals, reflect the internal structure and physical composition of its deep folded basement formed by thick complexes of magnetic rocks.

Certain similarities in magnetic anomalies of the Bol'shezemel'skaya tundra with those in the interior of the Russian platform led some students to agree with old concepts of A. P. Karpinskiy [9] on the existence in the Bol'shezemel'skay tundra of a buried Pytkov Kamen block which had brought about the complex bending of Uralian structures (O. A. Kalinina, 1954; M. V. Kas'yanov, 1955; E. E. Fotiadi, 1955); or suggested to them that a "Bol'shezemel'sk Precambrian Shield" is the folded basement of the northwestern Russian platform (R. A. Gafarov, 1955).

However, the definite banded structure of the Bol'shezemel'sk magnetic zone with its generally northwesterly trend of magnetic anomalies, corresponding to the trend of folding in Timan schist, suggests rather that the basement in the entire outer northeastern corner of the Russian platform has been formed by Baykalian folding, as postulated by N. S. Shatskiy as early as 1935, and as recently concurred with by N. P. Kheraskov (1953), E. E. Fotiadi [24] and a number of others [5, 7, 11], on the basis of new geologic and geophysical data. This conclusion is corroborated first of all by the fact that Bol'shezemel'sk magnetic anomalies within the western Uralian slope are directly related to thick Upper Riphean volcanic complexes (Sablya, Yengane-Pe Ranges, etc.) which occur in meridional and northwesterly trending folds and are strongly magnetic. Judging from the projection of their corresponding banded anomalies, Riphean volcanics of the Urals probably extend far north and northwest under the sedimentary mantle, into the eastern part of the Pechora syneclise where they plunge deep to form its folded basement and to determine the generally highly intensive magnetic field of the Bol'shezemel'sk zone. Thus, the folded basement of the Pechora syneclise is essentially heterogeneous in its physical composition, being formed by Riphean schist in its western half and by sedimentary and volcanic rocks of the same age in its eastern half, corresponding areally to the interior zone of Baykalian folding.

The outer and inner zones (mio- and eugeosynclinal zones) of Baykalian folding in the northeastern part of the Russian platform are separated by a deep fault clearly marked by the Ilych-Chikshinsk and Pechora banded gravity maxima as well as by an abrupt change from the negative magnetic field to positive magnetic anomalies of the Bol'shezemel'sk zone. Associated with this fault, over a considerable distance is the Pechora swell system of platform folds.

On the whole, the Baykalian fold system in the northeastern part of the Russian platform and adjacent areas forms an immense virgate pattern, first noted by N. P. Kheraskov (1955), spreading out to the northwest and broken up

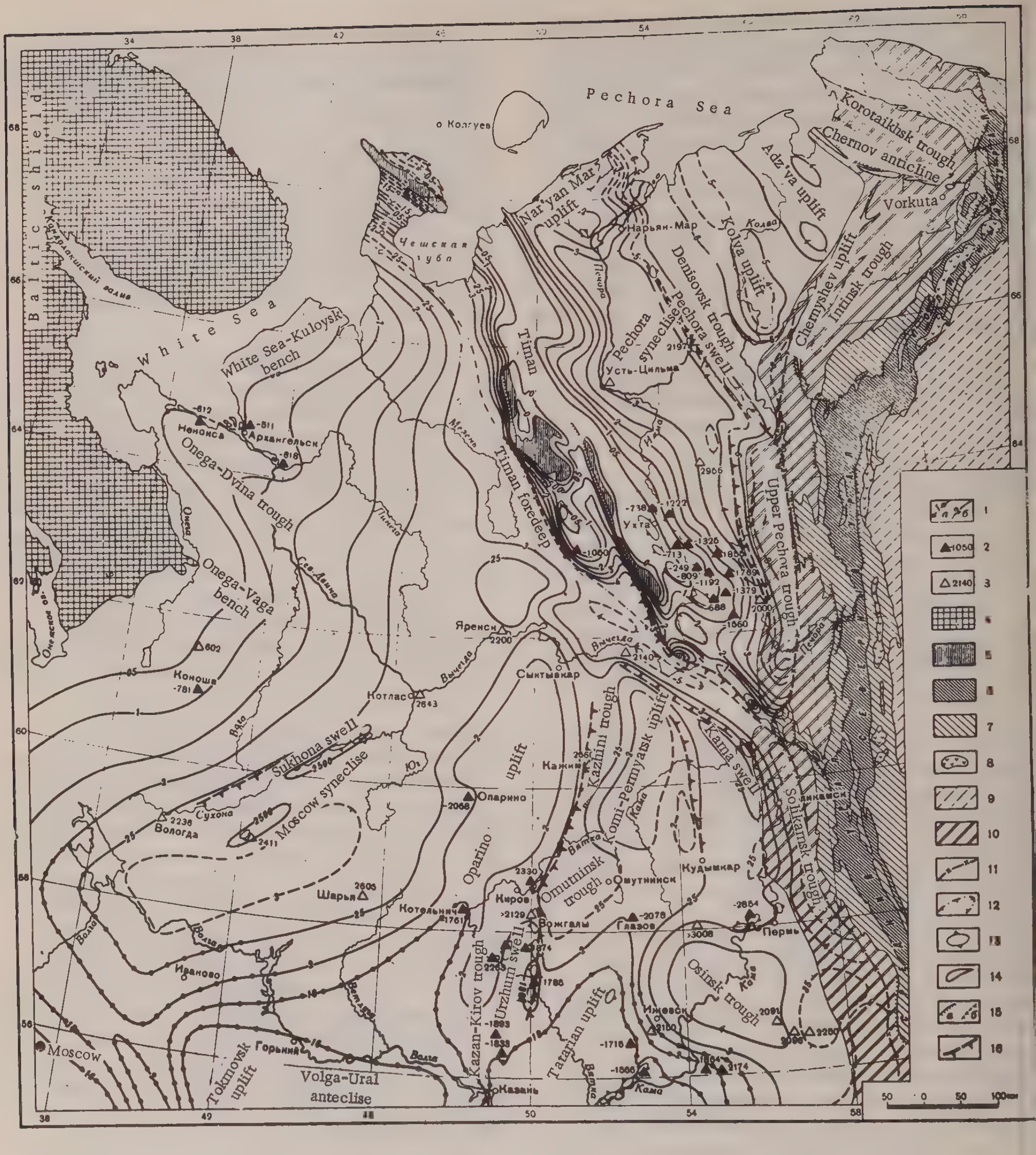


FIGURE 2. Surface structure of the Precambrian basement in the northern part of the Russian platform.

1 - structure contours on the Precambrian basement: a - from drilling data; b - from calculated depths of magnetic basement rocks and from drilling data; 2 - test holes reaching the basement (figures = distance below sea-level of basement); 3 - test holes short of basement (figures = total depth); 4 - Precambrian outcrops in the Baltic shield; 5 - outcrops of Riphean basement in Timan and Kola Peninsula; 6 - Precambrian outcrops in the Urals (lower structural stage of Hercinian folding); 7 - middle structural stage of Hercinian folding in the Urals (Ordovician, Silurian, Devonian, and Carboniferous deposits); 8 - basic to ultrabasic intrusions in the Urals; 9 - province of Hercinian folding underneath the sedimentary mantle; 10 - Uralian foredeep; 11 - boundary between the outer and inner zones; 12 - outlines of troughs in the interior zone of the Uralian foredeep; 13 - platform folds; 14 - anticlines in the Uralian foredeep; 15 - normal, reverse, and steep thrust faults: a - established; b - buried under the platform mantle and assumed; 16 - tectonic breaks (deep faults, regional flexures, etc.).

into a number of zones, with Timan being the extreme west branch.

III. SURFACE STRUCTURE OF THE PRECAMBRIAN BASEMENT IN THE NORTHERN PART OF THE RUSSIAN PLATFORM

The present structure of the Siberian platform is best represented on a relief map of its folded basement (Figure 2) which we have compiled for areas north of 58° North latitude, from drilling data and from numerous computations (about 3500) of the depth of the magnetic basement rocks. The commutational error in our method of tangents, with correction factors by V. K. Pyatnitskiy [22], is ± 15 to 25%, on the average.

Contours were drawn after a careful study of the gravity anomalies. As a rule, principal uplifts and troughs in the basement surface are outlined by the corresponding maximal and minimal gravity zones.

Principal structural and morphologic elements in the basement surface for this part of the Russian platform are the east slope of the Baltic shield, the Moscow syneclise, northern part of the Volga-Ural anteclise, Timan uplift, and Pechora syneclise, all complicated by a number of uplifts, sinks, and troughs [2, 22, 31, 33]. Many of these features, shown on a generalized map of the basement [2] have been described before, under the same or different names, by A. A. Balakirev [2], V. D. Nalivkin [5], E. E. Fotiadi [24] and others. However, aeromagnetic data, in conjunction with drilling and gravimetric data, make it possible to refine the position, form and size of some of the features.

The eastern slope of the Baltic shield is fringed by a number of large structural noses (buried basement shelves) plunging southeast and separated by northwesterly trending troughs. The latter jut off in festoons from the deep Moscow syneclise.

A large structural nose (Onega-Vara), outlined by the minus 1.5 km contour, is located on the southeastern extension of the Vetrenyy (Windy) Range of the Baltic shield karelids. It is bound on the northeast by the Onega-Dvina trough [26] which trends northwest toward the Onega Peninsula, and gradually levels off in that direction.

The Arkhangelsk basement bench, noted earlier by A. I. Zoricheva [6], from drilling data at Nenoksa, Arkhangel'sk, and Ust-Pinega occurs in the North Dvina estuarine area, and is traceable to the southeast for about 200 km, through the aeromagnetic data.

In the north, it is separated by a saddle from the Belomorsk-Kuloysk basement bench extending along the White Sea coast and clearly reflected by the gravity maxima.

The eastern slope of the Baltic shield bounds, on the northwest, the vast Moscow syneclise which extends northeast over a long distance to the middle course of the Mezen where it merges with the Timan foredeep first identified by E. E. Fotiadi [24] from gravimetric data.

The Moscow syneclise, as often noted by N. S. Shatskiy [31-33], is the most important and most typical structure in the Russian platform, and with a long and complex history of development. Its sedimentary section begins with Riphean Valday rocks [16, 34] which filled it at early stages. However, participating in its deep structure are trough-like downwarps (Onega-Dvina, etc.) filled up with more ancient Riphean deposits grouped as the Nenoksa formation [6, 16]. On the whole, this major negative structure is characterized by low negative and positive gravity values. Present in its central part, from Kotlas to Vologda, is a zone of strong gravity minima probably reflecting a system of deep basement faults.

The northwestern limb of the Moscow syneclise is complicated by the Sukhona swell, along which the basement is raised up to 2 or 2.5 km. Its southeastern limb, too, is complicated by the large Oparino domal uplift [2, 4, 5] which with the Kotel'nich dome constitutes a discrete zone [2] and the huge Tokmovsk uplift of the Volga-Ural anteclise, to the south; their structure has been determined by drilling [2, 15, 24]. In the central part of the Oparino uplift, the basement surface has been raised (according to aeromagnetic data) as high as about 1.5 to 1.8 below the surface. This uplift is not reflected in the structure of upper Paleozoic and Mesozoic deposits because, as early as the Devonian, its area was involved in regional subsidence related to a southeasterly shift of the axis of the then active Moscow syneclise [32].

In the east and southeast, the Oparino uplift is bounded by the Omutninsk and Kazhim troughs [4] which are, along with the Osinsk trough of E. E. Fotiadi [4, 24], the zones of deepest subsidence of the basement within the vast upper Paleozoic Glazovsk syneclise [33]. The Omutninsk trough is located in the southwestern part of the syneclise, separating the Oparino uplift from the large Tatarian uplift of the Volga-Ural anteclise; the latter was studied with deep exploration drilling and is described in a number of works [2, 4, 15, 24]. In the central part of the comparatively flat Omutinsk trough, the basement occurs at about 2.8 km, according to aeromagnetic data. Its southwestern limb is complicated by a fault and the associated Urzhum swell [4] which, in turn, is bounded on the west by the Kazan-Kirov trough [4].

In the north, the Omutinsk trough joins the linear Kazhim trough which opens up in the north into a deep trough of the southwestern Timan region. It is marked over its entire length by a linear gravity minimum which merges in the north with a regional Timan-front minimum. In its structure, the Kazhim trough is a narrow graben filled with thick Riphean deposits; they have been penetrated within it by a stratigraphic test hole at Kazhim village [4].

In the late Paleozoic, the Omutinsk and Kazhim troughs were involved in a regional subsidence of the vast Hercinian Glazovsk syneclise [33] which also included adjacent parts of the northern margin of the Tatarian uplift and the southeastern part of the Komi-Permyatsk uplift [4], which is traceable on a general north-northwestern trend for about 400 km, and has a width of about 200 to 250 km. In the crestal part of the uplift, outlined by a gravity maximum, the basement occurs at depths of about 1.5 to 1.8 km. Along the Uralian foredeep boundary, the eastern slope of this uplift is complicated by the Kama swell [4, 29], east of which the basement plunges abruptly along faults in the Solikamsk trough [15, 29].

In the north, the Komi-Permyatsk and Oparinsk arched uplifts are bound by the pronounced Timan foredeep [5, 17, 24] traceable in the southwest Timan region over a long distance from Polyudov Kamen in the southeast to Cheshskaya inlet in the northwest. In the axial part of this trough, along Vychegda River, the folded Karelian basement plunges to 5 or 6 km; and to about 3 or 4 km in the northwest, in the area of the big bend of the Mezen.

Participating in the structure of the Timan foredeep are extremely thick Riphean platform formations as well as Paleozoic rocks [6]. Thus, a zone of deep subsidence was formed in the Riphean along the edge of the epi-Karelian Russian platform and along its boundary with the Riphean geosynclinal zone of Timan; its formation continued after the geosynclinal conditions in the latter had ceased. Large subsidences within the Timan foredeep took place also during the Devonian, Middle Carboniferous, and Early Permian [6]. This trough is characterized by a number of specific features which set it apart from standard platform structure of the syneclise type, first of all by its unusually long and narrow shape with a very great depth. It appears that in its structure and development, the Timan foredeep should be assigned to "zones of pericratonic subsidences" designated recently by Ye. V. Pavlovskiy [17].

In the northeast, the Timan foredeep is bounded by a complex block massif of Timan, broken up by north-northwesterly faults into a number of horsts where the folded Riphean basement is exposed. The horsts are separated by graben-like troughs.

Traceable in Timan, northeast of the zone of schist outcrops, is a zone of buried basement benches; present in its extension in south Timan is the large Ukhta brachyanticlinal fold and smaller placanticlines, i. e., gentle anticlinal structures originating in a vertical movement.

Northeast of the Timan uplifts, the folded basement plunges gently into the Pechora syneclise, down to 3 or 4 km.

The vast Pechora syneclise is complicated by many local uplifts and subsidences with a general northwesterly trend [5, 7, 11, 24]. Its western flank is fringed by major structural noses in the middle course of Izhma River and in the Tobsh basin, and by the Nar'an-Mar uplift in the north. The latter is clearly marked by a gravity maximum. At the crests of these uplifts, the basement occurs at about 1.5 to 1.7 km and plunges comparatively rapidly into the adjacent troughs. The southwest slope of this uplift is complicated by a belt of platform folds.

In the Pechora swell and the Lem'yu-Chikshinsk gravity maximum belt to the south, the basement plunges rapidly to the northeast into the Denisovsk linear trough [5, 7] and into the outer (western) zone of the Timan foredeep. This zone of abrupt basement subsidence, related to deep faults, is a regional structural bench with associated steep platform folds of the Pechora swell plainly marked by banded gravity maxima.

The Denisovsk downwarp is characterized by its narrow trough-like form and extends northwest for over 400 km. In the southeast, it opens into the Uralian foredeep. Along its entire length, this downwarp is clearly reflected in a gravity minimum band which merges with the Ural-front regional minimum in the southeast. The basement is about 6 to 7 km deep in the axial part of the Denisovsk downwarp. In the northeast, the latter is bounded by the Kolva uplift [5, 7] reflected in gravity maxima. In that uplift, the basement occurs at 3 to 4 km, as it does northeast of there, within a flat and broad Adzva uplift [7] in the marginal part of the platform.

Platform structures of Timan and the Pechora syneclise, with their generally northwesterly trend consistent with Baykalian folding, are cut abruptly in the east and southeast by deep troughs in the northern part of the Uralian foredeep which constitutes the boundary between Hercinian folding of the Urals and the epi-Riphean Russian platform.

SUMMARY

1. Data of stratigraphic and deep exploratio[n] drilling, in conjunction with regional geophysic[s]

studies bring to light fairly definitely the general structural features of the Precambrian folded basement in the northern part of the Russian platform.

2. These new data have fully corroborated the concept of a heterogeneous structure of the folded basement of the Russian platform [1, 24, 30, 32] made up of various Precambrian systems.

The basement in the outer, northeastern corner of the platform, within Timan and the Pechora syneclise, was formed by the youngest Baykalian Precambrian folding, while the principal pre-Timan northern segments of the platform had been produced in the Karelian folding embracing large Archean blocks (Belomorsk, North Dvina, Volga-Ural, Oka-Volga massifs, etc.).

3. Regional geophysical data substantiate the concepts of N. S. Shatskiy [31], Yu. A. Kosygin [12], A.V. Peyve [18], E. E. Fotiadi [24], and others, on the importance of deep faults in the basement structure. These faults broke up the basement in Riphean time, into a number of major upthrown and downthrown blocks definitely reflected in the magnetic and gravity fields. As a rule, major basement faults are reflected in the mantle structure as a system of asymmetric and flexure-like folds with a corresponding trend.

Tectonic schemes of the Russian platform which do not account for the cardinal role of deep faults in its structure can no longer be regarded as well substantiated.

4. Regional geophysical data, supported by deep drilling, considerably refine our knowledge of the structure of the eastern slope of the Baltic shield, the Moscow syneclise, the northern part of the Volga-Ural syneclise, Timan, and the Pechora syneclise identifying a number of new structural elements such as the Timan foredeep, Oparinsk and Komi-Permyatsk arched uplifts, and other smaller features.

5. Participating in the deep structure of the Moscow, Pechora, and Glazovsk syneclises are trough-like downwarps of the graben type (Onega-Dvina, Kazhim, Kazan-Kirov, Denisovsk) which broke up the basement in the Riphean into a number of major massifs which subsequently became typical platform syneclises [16, 34].

6. The discovery of new major uplifts in the northern part of the Volga-Urals oil province (uplifts Komi-Permyatsk and Opatinsk), as well as the Kolva uplift and other structures within the Timan-Pechora area, tectonically promising for oil and gas exploration, is of importance in determining the trend of exploration.

7. Regional geophysics has become quite important in studying the structure of the Russian platform basement. Its role is particularly great in studying the deep tectonics of vast and poorly accessible expanses in the northern part of the platform.

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SOME FEATURES OF THE GEOLOGIC HISTORY OF TATARIA IN EARLY CARBONIFEROUS MALINOVSK, STALINOGORSK, AND TULA TIMES[1]

by

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Visean deposits in Tataria include the Malinovsk sequence (Upper and Lower Malinovsk beds),[2] and the Stalinogorsk and Tula horizons [1, 11, 14, 15]. This stratigraphic interval comprises parts of two major sedimentary cycles. Its lower part is represented by a regressive series of Lower Malinovsk marine beds, transitional Upper Malinovsk beds, and continental Stalinogorsk deposits. The latter gave place to a new sedimentary cycle which opened with shallow marine deposits of the Lower Tula horizon. At the close of Tula time, the marine basin was quite deep and persisted into Aleksinsk time.

Facies of this interval in Tataria were determined by three major structural zones: the northern and southern domes of the Tatar arch, and the Kama-Kinel trough separating them. The greatest change in facies took place in Early Malinovsk time; it decreased in intensity in Late Malinovsk and Stalinogorsk time and ceased completely by the end of Tula time. No distinction between facies zones has been observed in the Aleksinsk sequence.

Changes in the rate of progress of these structural zones were related to the cyclic development of structures of the first order (Kizelovsk-Visean-Namurian cycle; [10]).

EARLY MALINOVSK TIME

Deposition of Early Malinovsk beds in the northern and southern domes of the Tatar arch was preceded by a sedimentary break. Minor erosion affected the south dome, with only a small part of the Rakovsk limestones missing [4, 13]. Erosion on the north dome was considerable; here, Lower Malinovsk beds rest on Cherepets and locally on Likhvinsk rocks. Thus, foraminifera suggesting a Likhvinsk age were identified by L. F. Rostovtseva in limestones underlying a Lower Visean terrigenous member in two crestal test holes in the Krasnovsk uplift: in well No. 1, at 976.8 to 969.8 m, Vicinisphaera squalide Ant., Vangulata Ant., Parathurammina cushmani Sul., Chernyshinella cf. glomiformis Lip.; at 969.8 to 963.1 m, Archaesphaera minima Sul., A. magna Sul., Parathurammina cushmani Sul., Vicinisphaera angulata Ant., Bisphaera irregularis Bir.; in well No. 2, at 1002.2 to 995.2 m, Hyperammina minima Bir., Archaeasphaera minima Sul., Tubertian sp., Bisphaera irregularis Bir.

The problem of the floor of the Lower Malinovsk beds in the Kama-Kinel trough has not been cleared up. V. M. Pozner [12] believes that this section begins here with an erosional interval, as deep as the Ozersk-Khovansk beds. Other authors [3, 5] stress a gradual transition from Pozner's Lower Malinovsk beds to the underlying deposits.

Lower Malinovsk beds are largely shale, usually montmorillonite-hydromicaceous. Occasional limestones occur in the Kama-Kinel trough, while shales in the upper part of the interval carry some kaolinite. Lower Malinovsk beds contain plant detritus and fairly common siderite concretions.

Lower Malinovsk beds of the Kama-Kinel trough abound in marine fossils — brachiopods, gastropods, pelecypods, and foraminifera — which indicates their marine origin. No fossils have been found in the corresponding interval over the north and south Tatar domes. The montmorillonite-hydromicaceous composition of the shales, similar on the whole to the marine fossiliferous shales from the trough suggests that they, too, are marine. The absence of silty stringers points to the sluggish hydrodynamic activity of these segments of the basin. It is possible that stagnant conditions, unfavorable for a marine fauna, prevailed over the domes.

[1] Nekotoryye cherty geologicheskoy istorii tatarii v malinovskoye, stalinogorskoye i tul'skoye vremya nizhnekamennougol'noy epokhi.

[2] According to the resolution of the Interdepartmental Stratigraphic Committee (1960), the Malinovsk interval of V. M. Pozner is the Malinovsk epi-horizon at the base of the Visean; his upper and lower Malinovsk beds were named the Yelkhovsk and Radayevsk horizons, respectively.

Lower Malinovsk beds are 150 to 200 m thick in the Kama-Kinel trough, and drop abruptly to 2 to 6 m in the north and south Tatar domes. A paleogeographic map of this time accompanies a paper by M. F. Mirchink and R. O. Khachatryan [9].

LATE MALINOVSK TIME

The transition from Early to Late Malinovsk time is fairly gradual, although local unconformities at their boundary cannot be ruled out, especially in the Kama-Kinel trough.

Upper Malinovsk beds are made up of siltstone, sandstone, and shale, with fairly common carbonaceous shales and coal. Much plant detritus is present in all beds. The shales are hydromicaceous-kaolinite, with some montmorillonite in their lower part. Siderite concretions are common. Present in the upper part of this interval, in the Kama-Kinel trough, are limestone beds with foraminifera, and shale with brachiopods, trilobites, and conodonts. Neither limestones nor a marine fauna have been observed in this interval outside the trough.

The foraminiferal assemblage from Upper Malinovsk limestones differs but little from the Upper Tournaisian (Rakovsk). Prominent here are Tourniella and Tournaisian species of endothyres, while Visean forms (Haplophragmella, Tetrataxis, etc.), identified by N. P. Malakhova [6] in the Lun'yev horizon, are missing. A marker in the foraminiferal development of the Kama-Kinel trough was a Stalinogorsk continental interval, after which the foraminiferal assemblage was rejuvenated by the appearance of Visean species (Archaediscus, etc.). However, Malinovsk assemblages of goniatites, brachiopods, spores, and pollen carry many Visean species; we must, therefore, concur in regarding Malinovsk beds as Visean [14, 15]. A lag in the foraminiferal development may have been due to unfavorable conditions prevailing in the Kama-Kinel trough at that time (namely, the existence of an almost fresh-water basin; the prevalence of terrigenous sediments).

Common among Upper Malinovsk beds are fine-grained well-sorted sandstones deposited apparently by marine currents, although their deposition in delta channels cannot be ruled out. These sandstones alternate with beds carrying stigmaria in their live position, also carbonaceous layers, which suggests a vegetation cover. An alternation of soil formations and sandstones suggests a corresponding alternation of areal conditions. It is therefore reasonable to assume the presence of a shallow Late Malinovsk basin with numerous islands overgrown with vegetation. These islands were periodically flooded or washed out, so that individual soil layers were of short duration, as witness their thinness and the lack of underlying rocks with a typical lumpy subsoil texture (a soil layer did not last long enough to modify the underlying rocks into a subsoil).

The presence of both marine (marine fossils, limestones) and continental criteria (soil layers, coal, an abundance of plant detritus) suggests a transitional marine-continental stage. This is corroborated by their position in the section between Lower Malinovsk marine and Stalinogorsk continental deposits.

Different sedimentary conditions prevailed within and outside the Kama-Kinel trough, in Late Malinovsk time (Figure 1). Limestone beds and the presence of a marine fauna in the trough suggest a temporary restoration of marine conditions. The sea occupied only the axial and probably the most depressed zone of this area. This was probably a freshened marine basin, judging from the many Estheria and Lingula and from the dwarfed aspect of the goniatites. The axial zone is marked by maximum sand thicknesses suggesting strong currents which distributed sandy material.

There is no clean-cut evidence of a temporary restoration of marine conditions over the south Tatar dome; no limestones and no marine fossils, with only well-sorted sands deposited most likely in a beach zone.

Upper Malinovsk deposits in the Kama-Kinel trough are about 100 m thick, with considerable longitudinal changes; they gradually wedge out to the north, being totally absent in the north dome and only 2 to 4 m thick in the south dome. The thickness distribution shows that the maximum Upper Malinovsk subsidence took place in the Kama-Kinel trough. The many coal beds here also indicate an intensive subsidence.

STALINOGORSK TIME

The Stalinogorsk horizon rests on an erosional surface, which is corroborated by the difference in age of the underlying beds. No typical basal horizon has been observed. Its absence may be due to the fact that the underlying deposits are unconsolidated and lithologically similar to the Stalinogorsk; for this reason, they could not provide suitable material for a basal horizon. Throughout most of Tataria, the Stalinogorsk horizon rests on Upper Malinovsk beds. The latter are missing in the north Tatar dome, where the Stalinogorsk horizon rests on Lower Malinovsk beds. In some areas of the south dome, on sites of pre- and Early Stalinogorsk channel cuts, Stalinogorsk deposits rest on Tournaisian limestones, with Upper and Lower Malinovsk beds missing in the cuts.

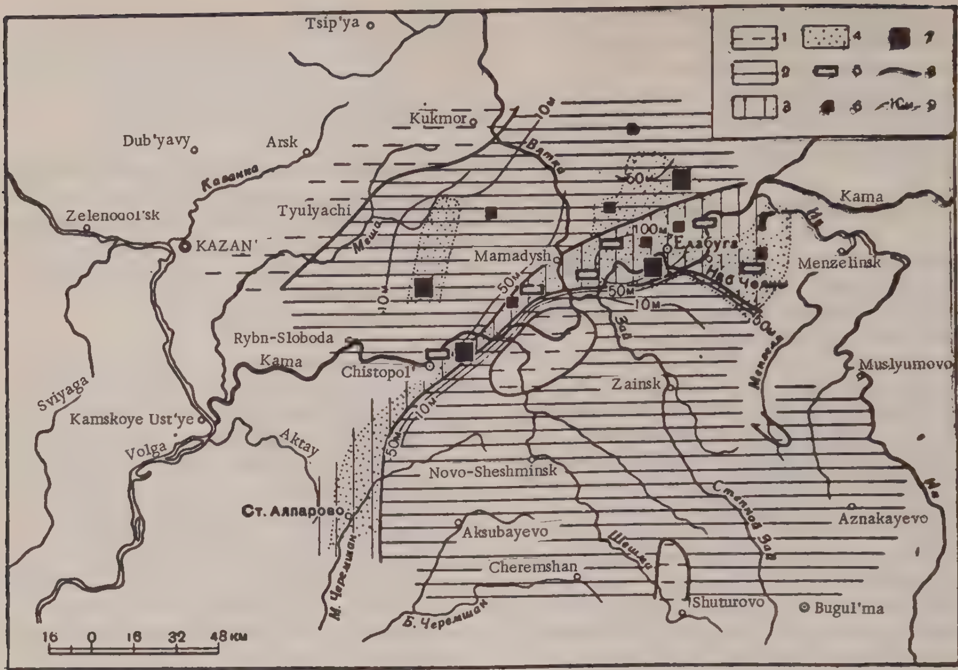

FIGURE 1. Isopach map of Upper Malinovsk facies in Tataria.

1 - deposits missing; 2 - alternating marine and continental deposits: well sorted sandstone, siltstone, shale, coal; 3 - same with limestone beds carrying a marine fossil; 4 - areas with a total thickness of sandstones over 10 m; 5 - test holes penetrating fossiliferous marine limestones; 6 - test holes penetrating a total thickness of coal beds up to 5 m; 7 - test holes penetrating a total thickness of coal, over 5 m; 8 - boundaries of facies zone; 9 - isopachs of Upper Malinovsk interval.

Throughout Tataria, with the exception of the extreme southeast, the Stalinogorsk horizon is made up of carbonate-free arenoargillaceous deposits (Figure 2). Marine fossils are missing and the argillaceous material is kaolinite. Common in the upper part are lenses of white kaolinite "biscuit" shales. These rocks are rich in plant detritus, with fairly common coal beds. All this suggests a continental origin for the Stalinogorsk deposits.

In southeastern Tataria (Krym-Saray, Shutrovo, Oykino), the upper part of this horizon contains limestones with the following foraminifera identified by S. G. Rakhmanova: Hyperammina vulgaris Raus. et Reitl., H. vulgaris var. minor. Raus.; Ammodiscus priscus Raus., Endothyra cf. crassa var. compressa Raus. et Reitl., Archaediscus ex gr. karreri Brady, A. cf. krestovnikovi Raus. forma magna (well No. 6, Oykino, 1079.5 to 1077.5 m). This assemblage is similar to that encountered by Ye. A. Reytlinger in Stalinogorsk limestones of Bashkiria. The presence of marine limestones in the upper Stalinogorsk horizon testifies to the marine condition of that time.

Most of the south Tatar dome was occupied in Stalinogorsk time by a marshy coastal plain with rivers; their channels are traceable as narrow bands of thicker and mostly sandy Stalinogorsk deposits. The highest part of the south dome was located between Buldyr, Grakhan, and Aktash, where Stalinogorsk deposits are the thinnest. Free loam was penetrated by the Chistopol well No. 8, in "biscuit" shales on the slope of this area [2]. Evidently, this marks the greatest intensity of desilicification of "biscuit" shales, leading to the appearance in them of free alumina.

In the Kama-Kinel trough, the Stalinogorsk horizon consists largely of coarse to mixed-grained sandstones quite different from the well-rounded Malinovsk sands. These sands are distributed in a narrow band along the axis of the trough. Apparently, the Kama-Kinel trough was the site of a major Stalinogorsk river. Lentils and lenses of coal which occur here point to individual marshy areas. The presence of a Lower Stalinogorsk river in the Kama-Kinel trough has been noted by N. I. Markovskiy [7], although the lack of stratigraphic detail on Lower Visean deposits

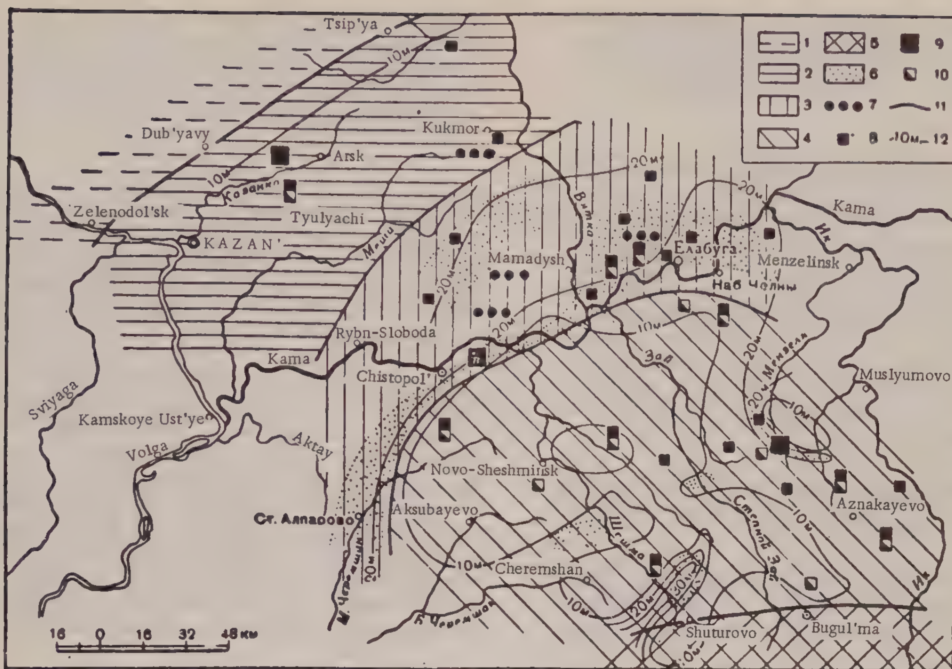

FIGURE 2. Isopach map of Stalinogorsk facies in Tataria.

1 - deposits missing. Continental deposits: 2 - watershed plain - sandstone, siltstone, shale; deposits of lakes, marshes, small rivers; 3 - main channel deposits - sandstone, chiefly alluvial; 4 - marshy coastal plain - sandstone, siltstone, shale; lacustrine, marshy, and alluvial deposits; 5 - continental to marine deposits; the lower part consisting of continental sandstone, siltstone, and shale, deposits of a marshy coastal plain; limestone and shale with a marine fauna in the upper part; 6 - total thickness of sandstone over 10 m; 7 - even- to coarse-grained sandstone; 8 - coal beds up to 5 m thick; 9 - coal beds over 5 m thick; 10 - kaolinite shales of the "biscuit" type (brittle, with organic remains); 11 - boundaries of facies zones; 12 - isopachs on the Stalinogorsk horizon.

prevented that author from differentiating Stalinogorsk sands from Upper Malinovsk sands undistinguishable from them on electric logs. He lumped them together as alluvial, thus considerably overestimating the thickness of the true alluvial sands.

In the north Tatar dome, the Stalinogorsk horizon is also free of carbonate rocks. N. I. Markovskiy [8] noted that local coals had been deposited in an environment more oxidizing then elsewhere in Tataria. The north dome area of that time was the most uplifted and adjacent to an area of no Stalinogorsk deposition to the northwest. It is probable that the north dome of that time was a watershed plain with headwaters marshes, lakes, and small rivers.

The Stalinogorsk horizon is 10 to 15 m thick in the south dome, as a rule; increasing to 20 or 30 m in the Kama-Kinel trough; decreasing to 8 to 10 m in the north dome; and wedging out to the northwest. Its thickness distribution shows that a differential sinking of the trough continued to some extent in Stalinogorsk time.

TULA TIME

The transition from Stalinogorsk to Tula time, in this area, was rather gradual. A transgressive Tula sea gradually advanced over the coastal plain, northwestward from southeastern Tataria.

Most of the lower Tula horizon consists of poorly sorted terrigenous rocks often carrying some calcium carbonate and many argillaceous and sandy limestone beds. The shales are hydromicaceous to montmorillonitic. Present in calcareous shales and in limestones are remains of a marine fauna of brachiopods, foraminifera, corals, and sponges. Tracks of mud-eating animals are common in all rocks. These features of the lower Tula horizon point to its shallow marine origin. Going upward, the volume of limestone increases at the

expense of terrigenous clastic rocks, with the appearance of foraminiferal-crinoidal limestone varieties almost free of insoluble residues. This suggests a deepening of the marine basin.

Often present in the upper half of the Tula interval in the north Tatar dome are dolomites, largely fine to medium grained, sandstone-like. They occur as transitional lenses in foraminiferal-crinoidal limestones and contain semirecrystallized crinoid remains. They appear to be sedimentary-diagenetic dolomite [16]. Less common are fine- to micro-crystalline dolomites free of argillaceous additions and organic remains. This variety is similar to sedimentary dolomite described by I. V. Khvorova [18].

The formation of dolomite indicates a rise in salinty in individual areas of the marine basin, brought about by climatic aridity.

An arid zone is known to have embraced, at the onset of the Visean, the Syr-Dar'ya basin, the sea of Aral, and the north Caspian region [17]. Toward the close of the Visean, this zone extended farther northwest, over the eastern and central parts of the Russian platform. It appears that some aridity prevailed in southeastern Tataria as early as the end of Tula time.

The Tula sedimentation conditions were different in different parts of Tataria (Figure 3). In the south Tatar dome area, the farthest removed foreshore, carbonate deposition prevailed, with limestones accounting for over half of the section. These rocks carry a rich and diversified marine fauna.

In the Kama-Kinel trough, limestones with a marine fauna are less common. Present in the section are beds of well-sorted sands deposited apparently by marine currents. The sand areas occur in two bands along the northern and southern sides of the trough. Present among Tula deposits are beds of coal and carbonaceous shale. These carbonaceous rocks are barren of root remains and occur with marine shales. They appear to be redeposited, having been formed from carbonaceous material

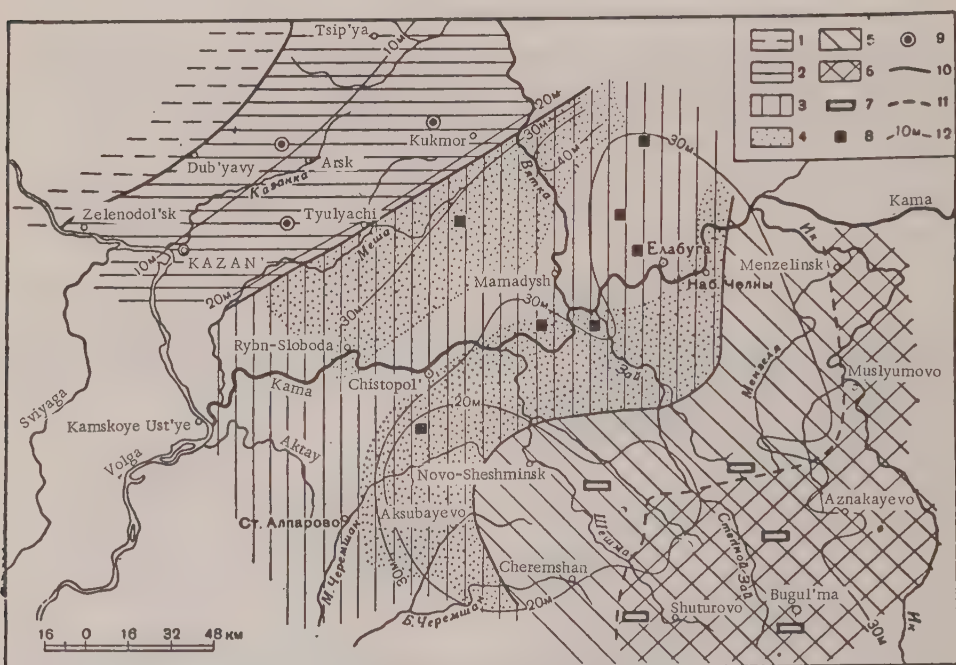

FIGURE 3. Isopach map of Tula facies in Tataria.

1 - deposits missing; 2 - shallow littoral deposits: siltstone, sandstone, shale, limestone; no marine fossils observed; 3 - deposits of a shallow sea with islands; siltstone, sandstone, shale, limestone; marine fossils present; 4 - fairly thick sandstone lenses (probably in the path of marine currents); 5 - offshore deposits: limestone, shale, siltstone; marine fossils common; 6 - same, with limestone making up over half of the section; 7 - dolomite; 8 - coal and carbonaceous shale; 9 - secondarily oxidized pyrite grains; 10 - boundaries of facies zones; 11 - boundaries of facies subzones; 12 - isopachs on the Tula horizon.

coming from islands. Thus, the Kama-Kinel trough of Tula time was a shallow sea with islands, and with currents depositing sandy material. An improverishment of its fauna appears to have been caused by an excess of terrigenous sediments.

In the north Tatar dome, the Tula horizon is made up of shallow marine formations: hydromicaceous-montmorillonite shale, siltstone, and sandstone. Limestone is rare, and no marine fossils have been found. Some areas of this littoral zone of the marine basin became shallow to temporarily dry, with reducing conditions giving place to oxidizing conditions. This is attested to by the presence of secondarily oxidized pyrite grains.

The Tula horizon is 25 to 30 m thick in the south Tatar dome, and about 30 m in the trough; it is reduced to 10 m in the north dome, and wedges out farther northwest. Its thickness distribution shows that preferential subsidence of the Kama-Kinel trough practically ceased in Tula time.

* * *

It appears from the above exposition that three structural zones in Tataria, the north and south domes of the Tatar arch and the Kama-Kinel trough separating them, controlled the distribution of facies and thicknesses of the horizons in question.

The Kama-Kinel trough was a zone of subsidence, the most intensive in Malinovsk time and gradually quieting down in the following periods. This subsidence was differential, as witness the presence of shallow and deep areas within the trough, in Early Malinovsk time [12]. This also was the probable reason for the presence of islands here, in Late Malinovsk and Tula time.

The south Tatar dome was little affected by the subsidence. Its highest part is located between Buldur, Grakhan, and Aktash.

The north Tatar dome stood the highest in this area. Upper Malinovsk deposits are missing here, with the other horizons considerably reduced in thickness.

Farther northwest, there lies an even higher area where terrigenous deposits of the lower part of the Visean are missing.

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BRIEF COMMUNICATIONS

SOME RESULTS OF THE STUDY OF THE EARTH'S CRUST IN THE KURILE ISLAND ARC PROVINCE AND ADJACENT AREAS OF THE PACIFIC, FROM DATA OF DEEP SEISMIC SOUNDING[1]

by

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Deep seismic sounding in a transition zone from the Asian continent to the Pacific, carried out by the Soviet Union in 1957 and 1958 [3], has yielded data on the crustal structure of the Okhotsk and Bering Seas and of adjacent areas of the Pacific. The Kurile island arc and adjacent areas of the Pacific are particularly interesting because of the great diversity of their structure in the comparatively narrow belt of about 300 to 400 km.

A general analysis of seismic data reveals the structural changes in the crust throughout this zone and its differentiation into three main types, the continental, oceanic, and transitional, as have been done before [1].

The continental type crust, according to the present concept [7], consists of three principal rock complexes: the upper sedimentary; and two lower ones, tentatively named here "granite" and "basalt" layers. The total thickness of the continental crust in this area is not over 20 to 30 km, i. e., not greater than that of platform provinces [4, 7]. The average propagation velocity of longitudinal waves in a continental type crust is not over 6. 0 km/sec.

The oceanic type crust is represented here, as it is in most studied areas of the world ocean, by two layers: a thin sedimentary layer, less than one km thick, and a "basalt" layer 5 to 10 km thick. The average propagation velocity in this type of crust, not considering the sedimentary layer, is about 7 km/sec.

We designate as transitional those types of crust intermediate between the two others in thickness (10 to 20 km) and the combination of thickness and composition of their component layers.

The differentiation of this province into areas of different crustal types was done on the basis of correlation of time-distance curves for advanced waves with relationship curves for average velocity V and depth h, constructed from them.

Figure 1 presents time-distance curves for advanced waves; they are grouped in three time zones, with "continental" curves showing the maximum time, and the "oceanic", the minimum. Constructed from these were $\overline{V}$ (h) curves. They, too, are grouped in three areas of $\overline{V}$ values, with "continental" curves showing the maximum values, and "oceanic" — the minimum. Examples of such curves are given in Figure 2.

Areas of different crustal types can be seen in Figure 3 which shows the distribution of various types of time-distance and $\overline{V}$ (h) curves. The boundaries between these areas cannot be drawn accurately because of the inadequate density of shooting lines.

This map shows that the complex alternation of all three crustal types takes place both away from the islands to the oceanic plateau and along the area in question — the island of Hokkaido to Kamchatka. The most complex and diversified structure occurs in a zone between the island arc and the deep trough. On the basis of structure of the crust, this zone can be divided into three parts: the northern, central, and southern.

The northern part, adjacent to the southern tip of Kamchatka and northern islands of the

[1]Nekotoryye rezultaty izucheniya stroyeniya zemnoy kory v oblasti kuril'skoy ostrovnoy dugi i prilegayushchikh uchastkov tikhogo okeana po dannym glubinnogo seysmicheskogo zondirovaniya.

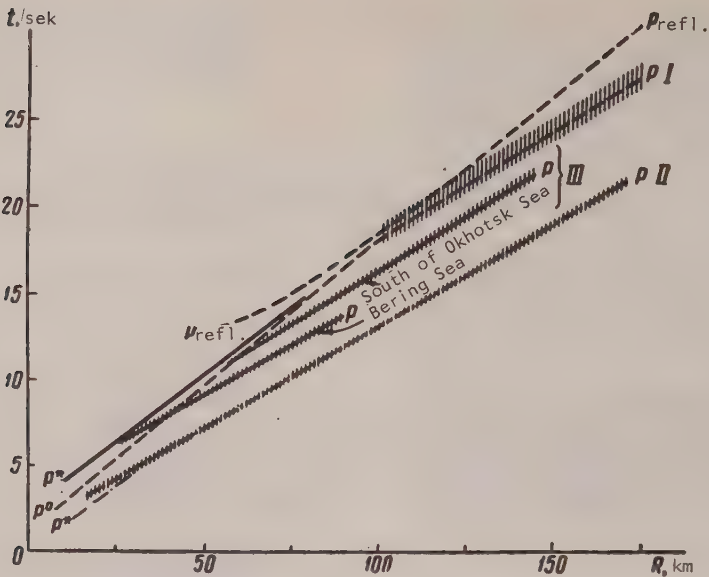

FIGURE 1. Main types of time-distance curves.

I - continental; II - oceanic; III - transition. Differentiated in Type III are curves for the Bering and Okhotsk Seas.

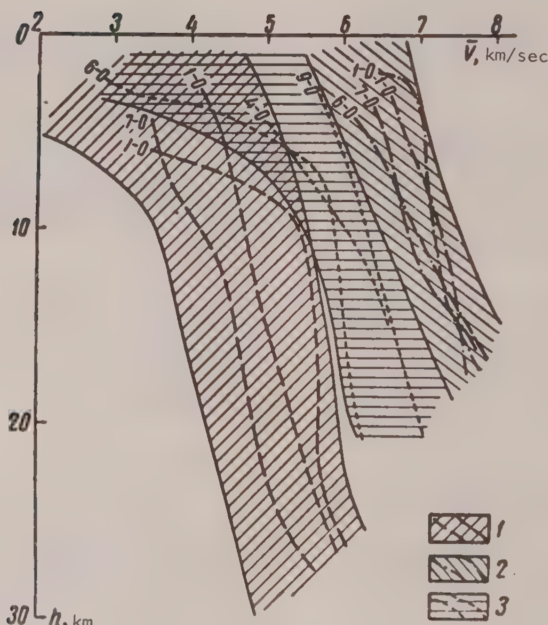

FIGURE 2. Examples of $\overline{V}$ (h) curves, and provinces characterized by various types of curves.

1 - continental type; 2 - oceanic; 3 - transition.

Kurile arc, as far as Kruzenstern Strait, consists entirely of the continental type crust.

The southern part, including the area south of Bussol Strait, is differentiated into two types. Present on the western slope of the trough, with bottom depths of 1 to 5 km is a continental crust zone, while Urup, Iturup, and Kunashir islands adjoin a transition zone.

The central part, between the straits of Bussol and Kruzenstern, is also characterized by two zones. A transition-type crust lies immediately under the islands and west of them. East of the islands, segments of oceanic crust occur along with the transitional.

Areas of continental crust within this province are fringed by relatively narrow bands of transition crust, which coincide in the north and south with the direction of the deep trough axis. In the central part, both bands veer to the west and merge with a large segment of transition crust, between the Bussol and Kruzenstern Straits. This segment is coupled to the deep part of the Okhotsk Sea, with the same type of crust.

Oceanic-type crust is present in the eastern part of the transition zone.

Curves of change in average velocity $\overline{V}$ along shooting profiles, at a depth of h = 7 km from the bottom, have been drawn for a better representation of changes in the velocity profile, in going from one type crust to another, and for a better representation of its relationship with bottom relief.

Figure 4 presents such curves and bottom relief for shooting lines across the trough, as well as composite curves along the island arc and along a line parallel to it, out in the ocean, east of the Kurile-Kamchatka trough.

A correlation of the velocity curves and bottom relief (Figure 4-a, b, c, d) shows a definite regularity; the highest values of average velocity $\overline{V}$ correspond to the oceanic plateau. The change from the latter to the shelf zone, in the north and south, is marked by a sharp velocity drop in the eastern slope of the trough.

The shelf zone is marked by low $\overline{V}$ values because of the presence here of comparatively thin sediments. The lower $\overline{V}$ values have been observed near Kamchatka (Figure 4-a) where sediments are the thickest.

Quite conspicuous in the curve along the island arc (Figure 4-e, curve 1) is an area of higher $\overline{V}$ values, from the central and southern parts of the arc.

The curve constructed for the oceanic plateau (Figure 4-e, curve 2) is marked by high $\overline{V}$ values of about 7.0 km/sec and is practically parallel to the horizontal axis, which testifies to the stability of $\overline{V}$ values in the ocean.

The differentiation of this province into areas

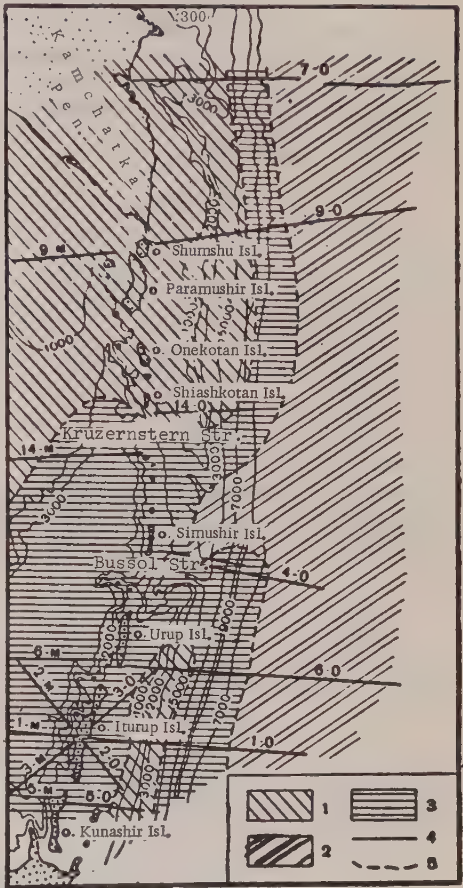

FIGURE 3. Structure of the crust in the Kurile island arc province, in the Kurile-Kamchatka deep trough, and in adjacent areas of the Sea of Okhotsk and the Pacific.

1 - areas of continental structure of the crust; 2 - areas of the oceanic type; 3 - transition type areas; 4 - boundaries of these areas; 5 - seismic lines.

of different crustal structure is reflected in bottom relief [2, 9], the magnitude of gravity anomalies (A. G. Gayyanov, L. P. Smirnov), the nature of volcanism [5, 8], seismicity [6], and the recent tectonic movements [5-a].

According to bathymetric data, large shallow areas (less than one km deep) are present between the island arc and the deep trough in the north and south parts of this province [2, 9].

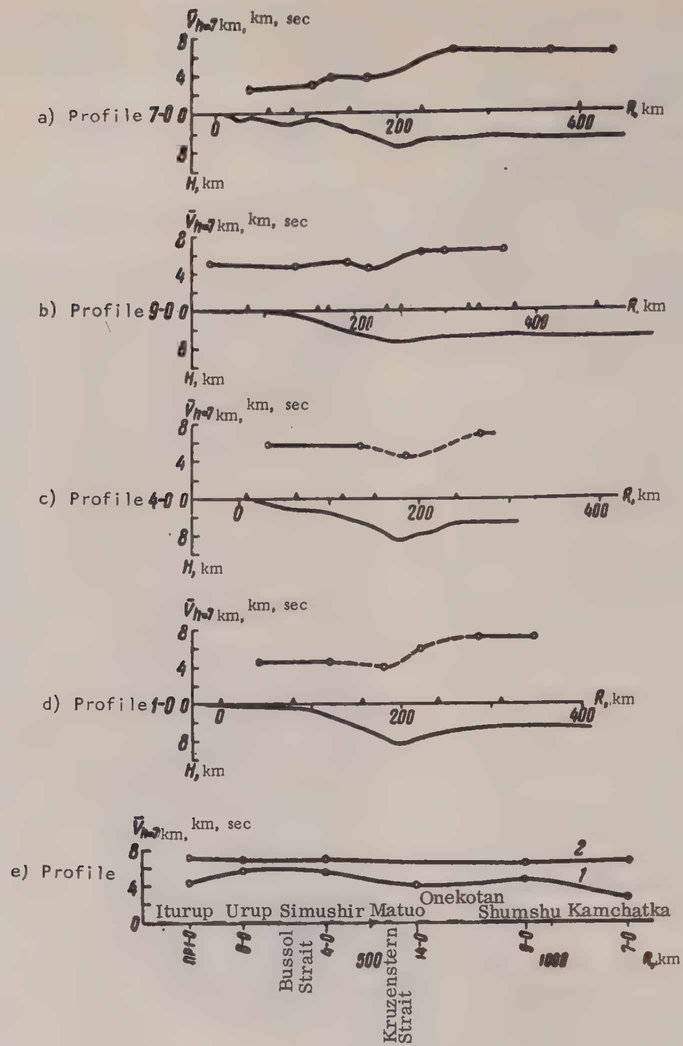

FIGURE 4. $\bar{V}_{h\,=\,7\ km}$ curves along lines (a, b, c, d) crossing the trough and along line (e) parallel to it.

1 - curve along the island arc; 2 - curve along line parallel to the trough and located on an oceanic plateau.

The shelf zone narrows down in the central zone between the Bussol and Kruzenstern Straits. A deep water embayment ($H > 2$ km) exists adjacent to the islands and joins the Okhotsk Sea by way of deep straits (Figure 3).

A comparison of bathymetric data with the structure of the crust shows that shallow areas of the Pacific near the northern and southern islands of the arc are associated with a continental-type crust. A deep area near the central islands of the arc corresponds to a transition-type of crust.

This regularity is also well expressed near the west coast of the island arc. Those areas where great depths ($H > 2$ km) occur near the islands (the central and southern parts of the arc) are marked by a transition-type crust; areas with a wide shelf zone (northern islands) are marked by continental-type crust.

A correlation with gravimetric data shows that areas of continental-type crust are associated with lower values of Bouguer gravity anomalies, compared with their values out in the ocean. Areas of transition-type crust are

associated with the anomaly values intermediate between the oceanic and continental. The boundary pattern for areas with different values of Δg is similar on the whole to that for different crustal structural zones.

A. V. Goryachev's analysis of statistical data [5-a] has shown that the most intensive volcanic activity for the last 200 years occurred in the central segment of the arc, which is characterized by a transition-type crust.

Earthquake data for this area [5, 6, 8] reveal a higher seismicity for areas of continental crustal structure, compared with transition and oceanic crustal areas. Intensive recent movements are distinctive features of the present-day tectonics of the Kurile arc. The arc can be divided into three parts by the nature of these movements. The northern and southern parts are marked by intensive uplifts while the central part, between the Bussol and Kruzenstern Straits, is subsiding.

It is to be hoped that further analysis and more careful correlation of seismic data with the results of other geophysical studies (gravimetry, magnetometry, seismology) as well as with the geologic structure of the arc, will shed additional light on regularities in the formation of the arc and the entire transition zone.

SUMMARY

As revealed by deep seismic sounding, the Kurile island arc and adjacent areas of the Pacific are marked by a complex crustal structure.

The zone between the island arc and the deep Kurile-Kamchatka trough is not a structural unit but is divided into northern, southern, and central segments. All of the northern and part of the southern segment are marked by continental-type crust, not far from large continental structures of Kamchatka and the islands of Japan. The central part is characterized by a transition-type crust and is a continuation of the deep segment of the Okhotsk Sea with a similar structure. These results are in accord with gravimetric data.

In the nature of its bottom relief, volcanism, seismicity, and recent movements, this zone is also divided into three parts.

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PNEUMATOLYTIC MONAZITE OF MALAYA LABA RIVER (NORTH CAUCASUS)[2]

by

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Monazite usually occurs in rocks as an accessory mineral, or crystallizes in pegmatites. We have encountered accessory monazite of a less common pneumatolytic origin, in association with orthite. The unusual paragenesis of these minerals and their extremely complex geologic occurrence have led us to a detailed study of this interesting mineralization in a crystalline section on the left bank of Malaya Laba River, North Caucasus [6].

Assorted crystalline schist, pagiogneiss, amphibolite, and ultrabasics intruded along bedding planes are involved in the structure of an ancient crystalline body. All these rocks have been regionally metamorphosed and affected by contact metamorphism in connection with the Urushten granitoid intrusive complex. Processes of Na-metamorphism, both regional and associated with an alaskite granitoid intrusive phase were prominent in the formation of these rocks. Conformable veins of pegmatoids and albitites with orthite and apatite, quartz-muscovite veins with apatite, and sulfate-carbonate veins with these minerals are common. Processes of locally superimposed albitization, carbonatization, and sulfatization are probably related to the last stages of the Urushten igneous complex.

Granitoid magmas reacting with serpentinite usually alter them to various amphibole- and talc-bearing compounds. A series of rocks, containing actinolite, phlogopite and talc derived from an ultrabasic magma is present in this area. They are involved in the structure of the crystalline body by alternating with its rocks in thin lentils and intercalations, and form a "layer cake" in exposures.

Lenticular pockets up to 4 cm thick, of apatite and orthite with an addition of monazite, zircon, albite, and chlorite are present among thin layers (10 cm) of talc-actinolite-carbonate rocks contacting albitized amphibolites and actinolitites.[3] Amphibole, biotite, talc, quartz, carbonates, celestite-barite, and hematite are present besides these.

These lenticular pockets are mostly apatite and orthite, crystallized at about the same time, as witness their intergrowths. On the other hand, the xenomorphic grains of apatite which fill up the interstices between orthite grains, together with aggregates of orthite replaced by apatite, show that apatite was crystallized somewhat earlier than orthite. Present in apatite are gas-fluid inclusions. As a rule, orthite and apatite contain a large number of minute (0. 3 mm long) crystals of zircon or of a metamictic variety, cyrtolite.

Monazite forms fine-grained aggregates with individual members seldom exceeding 0. 1 mm across. These aggregates occur mostly at junctions of orthite and apatite grains, whose edges they corrode or almost completely replace, leaving behind only fading relicts (Figures 1 and 2). In this process, apatite is replaced to a greater extent than orthite. Zircon and cyrtolite are preserved in monazite aggregates. Also present are "inclusions" of monazite grains in apatite and orthite as a fine "rash" in a rosary arrangement. These phenomena are present, as a rule, near areas of monazite aggregates; away from the latter, the number and size of these rosary arrangements decreases until they gradually disappear. In rock segments without monazite aggregates, the inclusions in orthite and apatite also are absent.

Interstices between orthite and apatite grains are filled with chlorite (pennine). Occasionally present among green foliate aggregates of this mineral are scales of brown-green biotite or colorless talc. At contacts with amphibolite, the amount of pennine in orthite-apatite pockets increases at the expense of orthite with the deposition of hematite and less commonly of carbonate, in fractures. On the whole, this orthite-apatite rock is broken up by a series of microfractures, commonly filled with younger minerals. The fractures are filled mostly with another variety of chlorite, brown-green delessite, and hematite. The latter is most common in monazite aggregates. Delessite also occurs in association with celestite-barite, in cavities — developing on their periphery from orthite, in thin-scale

[2]Pnevmatolito-gidrotermal'nyy monatsit r. maloy laby (severnyy kavkaz).

[3]Amphibolites were probably formed out of gabbroids (their Cr content is in the hundredths of one percent); talc-actinolite-carbonate rocks and actinolites from ultrabasics, as shown by their Cr content, in the tenths of one percent.

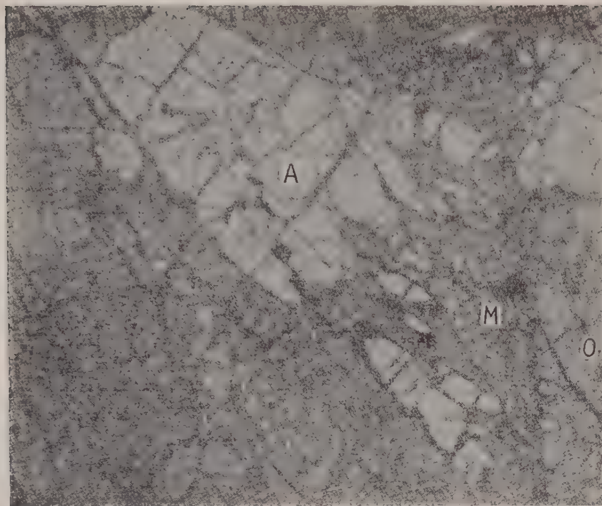

FIGURE 1. Simultaneously fading relicts of an apatite crystal in fine-grained monazite aggregate.

Magnification, 135 X, without analyzer. A - apatite; O - orthite; M - monazite.

aggregates with a relatively high birefringence and a positive elongation of individual scales. Central parts of these cavities are filled with celestite-barite, in ill-defined grains at junctions with delessite. Less common are quartz and carbonate veins, up to 0. 3 cm thick, which cut the orthite, apatite, and monazite aggregates.

Present in orthite-apatite pockets at their contact with albitized amphiboles are albite and residual amphibole. Most of the latter is replaced by orthite with grain edges corroded by albite.

Under a binocular microscope, individuals in monazite aggregates are discernible only

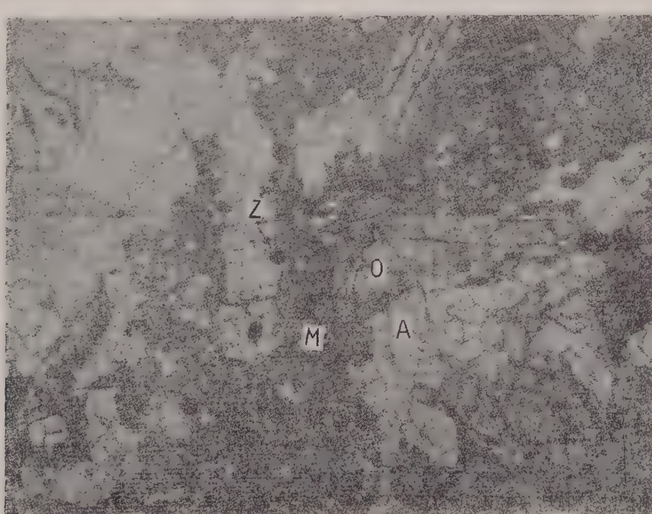

FIGURE 2. Orthite and apatite crystals corroded by fine-grained monazite aggregates.

Magnification, 20 X, without analyzer; A - apatite; O - orthite; M - monazite; Z - zircon.

Table 1

Interplanar distances of monazite from M. Laba River
Fe radiation, 2R = 57. 3 mm, d = 0. 6 mm

No.	M. Laba River monazite			Standard monazite		No.	M. Laba River monazite			Standard monazite	
	I	2l	d	I	d		I	2l	d	I	d
1	1	25.0	4.57	—	—	15	8	68.0	1.743	6	1.739
2	2	28.0	4.08	—	—	16	7	70.3	1.692	7	1.694
3	1	32.5	3.52	3	3.54	17	2	75.0	1.599	5	1.601
4	7	35.0	3.27	5	3.311	18	3	78.7	1.535	4	1.537
5	10	37.2	3.08	10	3.115	19	3	82.5	1.475	2	1.465
6	7	40.0	2.87	9	2.885	20	5	93.4	1.335	{ 4	1.361
7	1	42.7	2.69	—	—					5	1.328
8	1	44.5	2.59	—	—	21	4	98.9	1.278	5	1.278
9	2	47.3	2.44	3	2.455	22	6	103.5	1.236	5	1.227
10	1	49.0	2.36	2	2.359	23	1	109.0	1.192	4	1.193
11	4	53.0	2.19	7	2.197	24	2	111.5	1.174	4	1.171
12	7	54.9	2.12	8	2.130	25	2	113.8	1.158	—	—
13	4	59.7	1.961	6	1.968	26	2	124.0	1.098	4	1.103
14	8	63.0	1.867	7	1.866	27	2	129.8	1.070	4	1.0664
						28	5	135.0	1.049	3	1.0488

Note: In thin sections, monazite is colorless to red-brown because of the presence of iron oxides. It is optically positive, with 2V quite small; $\gamma = 1.873$; $\alpha = 1.787$; $\gamma - \alpha = 0.05$ [6].

with a considerable magnification. The monazite is white to red and brown-red; luster, vitreous; specific gravity, as determined by Ye. P. Pogodina, by the hydrostatic weighing method, is 4. 683 [6].

X-ray data by M. T. Yanchenko, are in fair accord with the standard for monazite (Table 1).

According to T. S. Magidovich, aggregates of this monazite, in reaction with HCl, break up into individual grains. This monazite is weakly soluble in HNO_3, without a preliminary fusing with Na_2CO_3, and tests phosphorus with ammonium molybdate.

An analysis of the Malaya Laba monazite, performed by D. N. Knyazeva in the laboratory of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Academy of Sciences, U. S. S. R., is as follows (in %): P_2O_5 — 26. 65, TR_2O_3 — 53. 98, ThO_2 — 2. 39, U_3O_8 — 0. 03, SiO_2 — 3. 90, TiO_2 — 0. 07, Al_2O_3 — 2. 70, (Fe_2O_3 + FeO) — 2. 05, CaO — 2. 86, MgO — 1. 69, H_2O — 1. 37, CO_2 — 0. 55, K_2O — 0. 24, Na_2O — 0. 35; total, 98. 83. Of interest is the almost equal content of TiO_2 in orthite (2. 42%; [6]) and in monazite. The higher content of additions in monazite is probably due to the presence of some orthite left behind in remnants of unaltered grains, and of hematite and carbonates in extremely fine fissures.

The chemical analysis data for monazite are in accord with its formula $CePO_4$ [10]. Inasmuch as thorium and other rare earths, besides cesium, may be the components of monazite, its formula is $(TR, Th)_{0.9}P_{1.0}O_4$.

An X-ray analysis of rare earths isolated from monazite (R. L. Barinsk, Institute of Mineralogy, Geochemistry, and Crystallography of Rare Elements, Academy of Sciences, U. S. S. R.) is as follows (in %): La_2O_3 — 22. 05, Ce_2O_3 — 53. 18, Nd_2O_3 — 16. 90, Pr_2O_3 — 5. 71, Sm_2O_3 — 1. 68, Eu_2O_3 — 0. 12, Gd_2O_3 — 0. 24, Dy_2O_3 — 0. 12, with total TR taken to be 100%.

In addition, a spectrographic analysis of monazite by F. I. Sumina has identified the following elements: Sr, Mn (in hundredths of one percent), Zr (in thousandths), and of Be and Cu (in ten-thousandths of one percent).

If the Nd content in the rare earths total of the Malaya Laba monazite be taken as a unit, the ratio of rare elements will be similar to that in hydrothermal monazite (Table 2).

It has been established by E. V. Weinstein, A. I. Tugarinov, and N. V. Turanskaya [1] that hydrothermal monazites differ appreciably from all others, namely "their La and Ce content is greatly increased while that of Sm is reduced to the point where its amount is difficult to determine. The relative content of Pr in monazites of different generations varies little, always in the same direction with relation to Nd as it does for La and Ce."

Table 2

Distribution of rare earths in hydrothermal and pneumatolytic monazite

Monazite	Ce/Nd	La/Nd	Pr/Nd	Sm/Nd
Malaya Laba River	3.15	1.30	0.34	0.10
Central Asia [1]	3.05	1.70	0.29	0.10

As regards rare elements, the nearest approach to this monazite is Central Asian monazite from a quartz vein [1]. The ratio of individual elements in rare earths of the Malaya Laba monzonite is consistent, on the whole, with that established by K. Murat, H. Roset, and M. Carron for standard cerium monazite [5], namely:

$$1.\ La + Nd = 42 \pm 2\ \text{ат.}\ \%;\ 2.\ Pr \approx const\ (5 \pm 1\ \text{ат.}\ \%);$$
$$3.\ Ce + Sm + Gd + Y = 53 \pm 3\ \text{ат.}\%\ .$$

The composition of rare earths in this monazite is better expressed by the graphic method of Ye. I. Semenov and E. L. Barinskiy [7]. Curves for odd elements in rare-earth minerals are, as a rule, similar to those for even elements, as is the case in our study (Figure 3).

On this basis, it appears reasonable to associate the origin of these rare earth minerals with a post-magmatic phase of the intrusion of Urushten granitoids into the crystalline body.

Albitization of the orthite-bearing amphibolites should be associated with hydrothermal vein albitites. This process was preceded somewhat by an influx of rare earths, Th, Zr, P, F, and other elements; as a result, and in the presence of pneumatolytic processes, amphibole was replaced by TR-bearing orthite and apatite (Figure 4).

Data published on orthites from different areas demonstrate the almost universal regularity of a close association between this mineral and amphibole or biotite [2, 3, 8, etc.]. It is unquestionable that the presence of alkaline and volatile elements, as well as a sufficient amount of iron in the lattice of rare earth and Th-bearing orthite, are essential for its crystallization. In acid igneous rocks, the relatively late liberation of rare earths and Th, bound in orthite, depends on the degree of enrichment of the residual granitoid melt, in alkalies and iron [8]. On the other hand, in a metasomatic pneumatolytic origin of orthite, the necessary amount of Fe and Ca is extracted from iron-bearing minerals in the country rocks. It follows that orthite and apatite in these pockets were formed out of rare earths and phsophorus brought in by fluids, and out of calcium and iron extracted from amphiboles in the country rocks. This is indicated by the presence in these pockets of amphibole partly replaced by orthite; and of apatite in amphibolites, developed on amphibole (Figures 4 and 5). Orthite and apatite crystallized prior to albite, as demonstrated by their occasional replacement by the latter, at the contact of orthite-apatite rocks and albitized amphiboles. The ratio of the rare earths and phosphorus, during the crystallization of orthite and apatite, was probably such as to preclude a formation of monazite.

Monazite crystallized after orthite and apatite, and partly at the expense of these two, with a new influx of emanations associated with pneumatolytic processes. New emanations caused a partial solution of orthite and apatite, with a liberation of certain amounts of rare earths and P.

Thus, material for monazite was provided by the rare earths and phosphorus extracted from orthite and apatite, and possibly from new additions of these elements brought in by later solutions. The equivalent amounts of Th in the Malaya Laba orthite and monazite suggest that

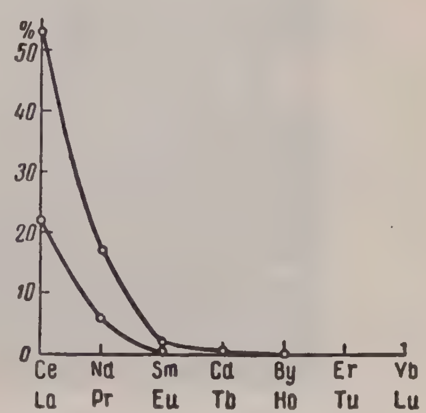

FIGURE 3. Composition of rare earths in residue of a pneumatolytic-hydrothermal monazite from the Malaya Laba River.

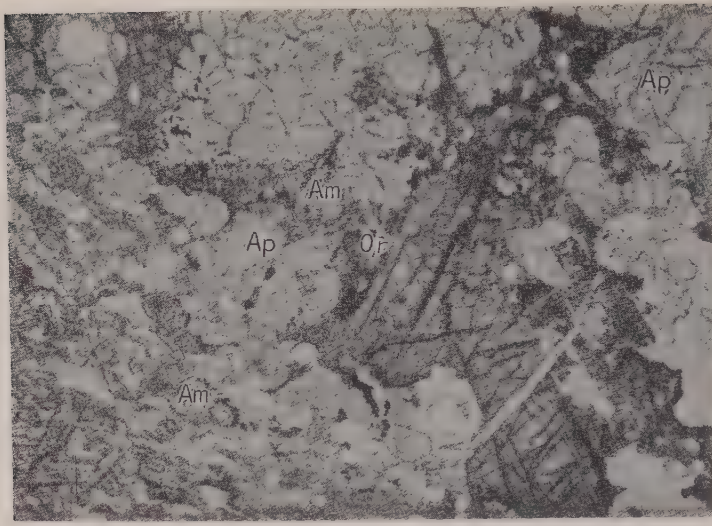

FIGURE 4. The formation of metasomatic orthite and apatite out of amphibole.

Magnification, 30 X, without analyzer. Ap - apatite; Or - orthite; Am - amphibole.

all thorium in orthite was fixed in monazite, without any additions from new emanations.

Hydrothermal minerals; i. e., pennine, delessite, albite, quartz, calcite, and celestite-barite, crystallized at a lower temperature. This process culminates evidently in the formation of low-temperature zeolites (?), crystallizing in small druses on miarolitic cavities. Such cavities have been observed in albitized amphibolites with orthite, apatite, carbonates, and sulfates.

It follows then that the Malaya Laba monazite is a metasomatic mineral formed in a pneumatolytic process, as demonstrated by the following facts:

FIGURE 5. Grain of metasomatic apatite in a crystal of common hornblende.

Magnification, 30 X, without analyzer. Ap - apatite; Or - orthite; Am - amphibole.

1) An aggregate nature, unusual for monazite, with unaltered residual crystals of zircon or cyrtolite, formerly imbedded in orthite or apatite.

2) The presence of simultaneously fading relict areas in apatite grains "corroded" by apatite; and of extremely fine monazite inclusions in orthite and apatite, as a "rash" in the vicinity of decomposed apatite and orthite grains.

3) The distribution of fine, rosary-like, monazite inclusions, and the absence of monazite inclusions in those segments of apatite and orthite free of monazite aggregates.

Thus, granitoids of the Urushten igneous complex are not monazitic, by themselves; however, conditions favorable for monazite crystallization are created at a certain ratio of rare earths to phosphorus, brought about by a partial solution of previously crystallized rare earth- and P-carrying minerals, and by newly-arriving batches of these elements, in a pneumatolytic process.

Of particular interest is the behavior of thorium in this process. As correctly noted by S. D. Turovskiy [6], there are many recent publications in world literature on the relatively great migrational capacity of thorium. The presence of pneumatolytic orthite and monazite corroborates S. D. Turovskiy's assertion of the great migrational capacity of thorium, under special conditions rarely realized in nature. One such condition, probably the most important, is a phosphorus-haloid-carbonate medium with alkaline metals [9]. Mineral associations in the above-described pockets, related to postmagmatic phenomena of the Urushten granitoid intrusions, indicate the participation of thorium in pneumatolytic processes determined by the alkali-carbonate medium with phosphorus and other volatile compounds; this corroborates the S. D. Turovskiy opinion.

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REVIEWS AND DISCUSSIONS

A FEW OBSERVATIONS ON THE NOMENCLATURE OF EXTRUSIVE ROCKS[1]

by

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Izvestiya, No. 11, 1959, carried a paper by Ye. K. Ustiyev, "On the Nomenclature of Extrusive Rocks". In that paper, the author proposed, as he did at the First All-Union Volcanologic Conference [4], to abandon the dual nomenclature of extrusive rocks and to adopt the "cenotype" scale as more detailed.

We believe that Ye. K. Ustiyev's suggestion is timely and reasonable; the nomenclature of extrusive rocks should be unified. However, this goal would not be attained by simply abandoning all paleotype names. The "cenotype" scale should be used rather as a basis for a more rational classification and nomenclature of altered extrusives.

Such a procedure appears to be simply unthinkable for the Urals with their widely developed Paleozoic volcanics altered to greenstone. On the other hand, a more careful study of the paleotype nomenclature reveals great confusion and a lack of elementary logic in the naming of rocks.

Ostensibly, paleotype and cenotype aspects of rocks have long ceased to be the age criteria, being merely a measure of their alteration. As a matter of fact, however, the principle of an age differentiation, or, what is even worse, of territorial differentiation, has been maintained. Mesozoic extrusives in the Urals are called basalts and dolerites, although some of them are altered. A great many of the Paleozoic extrusives in the Urals have not been altered; there are some very "fresh" rocks, as in the North Urals, where they are called paleolavas, paleobasalts, cenotype porphyrites, and other synthetic names.

Inasmuch as the terms "porphyry" and "porphyrite", denote both a paleotype aspect and a porphyritic texture, there is a need for names of paleotype extrusives without porphyroblasts. A. N. Zavaritskiy [1] proposed to name them aphyres and aphyrites, so that now one often hears such absurd names as "aphyric porphyrite".

We are used to the terms "porphyrite" and "porphyrite tuff"; if, however, "porphyrite" means an altered andesite, then we understand the term, "porphyrite tuff", to mean an altered andesite tuff rather than a tuff of altered andesite as the etymology of the term calls for. In other words, an extrusive rock, when altered, has a special name (andesite porphyrite instead of andesite; liparite porphyry instead of liparite; etc.), while the corresponding pyroclastic rocks keep the name "tuff", whose paleotype aspect is expressed by a complement rather than an adjective. Only long usage has bestowed upon such terms a semblance of correctness and necessity.

We also have been using the original names of intrusive rocks, such as gabbro, even when their original composition has been completely altered. Saussuritic, uralitic, and other gabbros have been identified in the Urals, while basalts (Paleozoic) and andesite, even if partially altered, are called porphyrites.

There is another common term, "albitized porphyrite", which is applied for some reason only to andesite- and andesite-dacite porphyrites with completely albitized plagioclase, although there is nothing in the name itself to indicate such a limitation. Moreover, the term "porphyrite", meaning an altered andesite, signifies primarily an albitization; it is difficult to see why albitization rather than chloritization is reflected in the name.

One often encounters the term, "albitized diabase", although "diabase", as a paleotype analogue of basalt, means an altered rock (evidently including albitization); otherwise, and in the presence of a dual nomenclature, it should have been called dolerite.

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[1] Nekotoryye zamechaniya k voprosu o nomenklature effuzivnykh gornykh porod.

The terms "greenstone porphyrite" and "greenstone diabase", proposed by A. N. Zavaritskiy [1, 2], essentially mean a greenstone stage of extrusive rocks in contrast to their diagenetic phase known as "porphyrite" and diabase. However, A. N. Zavaritskiy himself concedes the difficulty of differentiating between greenstone and diagenetic alterations in nature; their difference is not as substantial as that between paleotype and cenotype rocks (altered and unaltered). Such being the case, where do we begin to call a rock, "greenstone porphyrite" rather than plain "porphyrite", and why would it not be better to call an altered rock, "greenstone andesite", or better yet, "altered andesite", perhaps indicating the degree of alteration by adding, slightly, medium, and strongly, for lack of more precise terms?

The confusion is at its greatest in the nomenclature of acid paleotype extrusives. Paleotype analogues of liparites are known as "liparite porphyries", but this term is hardly used, especially in the Urals; paleotype extrusives supersaturated with silica are called quartz porphyries, quartz albitophyres, and, in the South Urals, quartz keratophyres. The vagueness of the terms "albitophyre" and "quartz albitophyre" has been noted by A. N. Zavaritskiy [1]. These names indicate in effect the mineral composition of porphyroblasts, as do the names, "augite porphyrite", "labradorite porphyrite", etc., for porphyrites. In a single nomenclature, we can call these rocks sodium liparites or sodium trachytes, with corresponding adjectives for altered varieties. The observation about "porphyrite tuffs" is even more valid for "albitophyre tuffs". If the names, albitophyre and quartz albitophyre are to be used only when the nature of a rock is not quite clear, as A. N. Zavaritskiy asks, then, what is "quartz albitophyre tuff" supposed to mean?

Literature on the geology of the Urals contains such terms as "amygdaloidal lavas" and plain "lavas", although they all refer to the same porphyrites, aphyrites, and even "greenstone porphyrites". The habit of using the paleotype name often leads to such "terms" as "andesite porphyrite lava", "quartz albitophyres, tuffs and lavas", etc., which are nothing but a petrographic lingo, perhaps understandable to their authors.

The practical uselessness of the "paleotype" nomenclature is not in the lack of terms corresponding to andesite-basalt, andesite-dacite, etc.; A. N. Zavaritskiy's terms, such as andesite-basalt porphyrite, andesite-dacite porphyrite, etc., along with basalt and andesite porphyrites, have been gradually becoming popular. In any event, the paleotype extrusive nomenclature is readily adaptable for new names corresponding to all subdivisions of the cenotype scale. The question is whether such names are necessary. When we say, "andesite porphyrite (aphyrite)" or "basalt porphyrite (aphyrite)", we are certain that these are andesites and basalts altered to some extent (the extent of alteration we cannot express in the term, porphyrite). By the same token, if we can say that a porphyrite is andesite-dacite or trachy-andesite, that means that its alteration is slight and it is quite superfluous to invent a new name for it; it is much simpler, more logical, and more expedient to call such a rock, altered andesite, altered andesite-dacite, etc.

Advocates of the paleotype nomenclature fear lest the distinction between altered and unaltered rocks be lost in a single nomenclature. To be sure, we are mindful of M. A. Usov's statement, "Extrusive rocks, in their altered state, are special forms entitled to special names" [3]. However, it is more rational to derive such names from those of unaltered extrusives.

Ye. K. Ustiyev states that the degree of alteration can be indicated by an adjective, "paleotype" or "altered". It is obvious that this degree of alteration not only can be but must be indicated in a name, both in its qualitative and quantitative aspect. Thus, along with retiring the paleotype nomenclature, a rational nomenclature should be worked out for altered extrusive rocks and for their derivative metamorphic rocks.

Metamorphic apoextrusive rocks should have names of their own; although, if they preserve the features of primary rocks, this fact should be reflected in their name, such as a quartz-sericite apoliparite, a schistose albite-chlorite apobasalt, etc. When the primary nature of a metamorphic rock is not clear, it appears to be expedient to classify it by its mineral composition, perhaps in conjunction with its texture.

It appears that the working out of a single rational nomenclature for extrusive rocks is the task for a special commission, but this task is urgent. The need for such a nomenclature is especially keen now, in connection with the ever growing study of paleovolcanism, paleogeography, and metamorphism.

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ON A SINGLE NOMENCLATURE FOR EXTRUSIVE AND VEIN ROCKS[2]

by

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Ye. K. Ustiyev's paper, "On the Nomenclature of Extrusive Rocks" [8] is quite timely and its thesis is unquestionably progressive. The author discusses the abandoning of the dual nomenclature now accepted in the U. S. S. R. for extrusive rocks, with their differentiation into "cenotype" and "paleotype", and proposes a single "cenotype" scale as more flexible and complete.

Ye. K. Ustiyev bases his proposition on the fact that the dual nomenclature, having originated in Western Europe with its real and sharp differences between ancient paleotype and younger cenotype extrusives, has been abandoned almost everywhere, by now; it has never been used in America, Japan, China, Australia, etc., i. e., in provinces approaching the Pacific zone. Nor is it being used by many Siberian and Far-Eastern petrographers. This is because those regions which contain intermediate Mesozoic extrusives along with those of Paleozoic and Cenozoic age, also exhibit a gradual intensification in "the natural post-magmatic alteration" in volcanic rocks, from younger to older.

On the basis of our experience with Mesozoic and Cenozoic extrusives of the Pacific belt, we wholeheartedly support Ye. K. Ustiyev's suggestion. Indeed, classic "cenotype" extrusives are rather uncommon not only among upper Mesozoic but among Cenozoic (Paleogene) volcanic formations, as well. At that, the latter often change along the strike to highly altered varieties. Often the sills accompanying the flows are much less altered than the contemporaneous extrusives, thus appearing to be more "cenotype" than the latter. Obviously, this shows that a paleotype alteration of rocks is brought about, as pointed out by Ye. K. Ustiyev, by the intensity and duration of exogenic factors, as well as by post-magmatic processes.

Unfortunately, Ye. K. Ustiyev has not pursued his thesis far enough. While noting quite correctly that a "cenotype" scale is much more comprehensive than the "paleotype", he fails to note that even this nomenclature is far from being perfect. Suffice it to say that it often lacks the clean-cut gradations between the families of extrusive rocks. For instance, dacites include a wide range of rocks corresponding in chemical composition to both granodiorite (with some adamellites) and quartz diorite, with different authors attaching a somewhat different meaning to this term. Again, Ye. K. Ustiyev's list of names does not include a number of extrusive rocks (such as extrusive analogues of plagiogranite and tonalite). He also makes no provision for rocks of the same composition but with a different texture; this makes it difficult to understand those authors who use the "cenotype" nomenclature alone, because the name of a rock tells nothing of its external aspect and textural features, a very important point with extrusives.

For these reasons, Ye. K. Ustiyev's nomenclature calls for more consideration and discussion. To be universally accepted, a cenotype nomenclature must be unified in the light of present-day knowledge.

More specifically, a convenient single nomenclature of extrusive rocks should be consistent with the nomenclature of their intrusive analogues. We present here an attempt at correlating the classification of basic rocks (excluding the ultrabasic) with Ye. K. Ustiyev's scale of cenotype extrusives, a composite of all the most effective and popular names extant.

It appears from this correlation that almost all intrusive rocks have their extrusive analogues in Ye. K. Ustiyev's nomenclature. It should be noted, however, that the three missing groups include more common extrusive rocks than intrusive rocks. If, as is possible, the extrusive analogue of alkalic K-granite (K-quartz keratophyre of the paleotype nomenclature) has been simply omitted by the author from his scheme and should have been named, like the Na-liparite — K-liparite, then indeed there would be no accepted names for analogues of plagiogranite and tonalite. We believe that the best name for extrusive analogues of

[2] K voprosu o yedinoy nomenklature effuzivnykh i zhil'nykh gornykh porod.

Intrusive rocks	Extrusive rocks
Alkaline-earth granite	Liparite
Alkalic K-granite	—
Alkalic Na-granite	Na-dacite
Adamellite[1]	Liparite-dacite
Granodiorite	Dacite[2]
Plagiogranite[3]	—
Tonalite	—
Quartz diorite	Andesite-dacite
Diorite	Andesite
Gabbro-diorite	Andesite-basalt
Gabbro (norite)	Basalt, dolerite
Alkaline-earth granosyenite	Trachyliparite
Alkalic K-granosyenite	K-trachyliparite
Alkalic Na-granosyenite	Na-trachyliparite
Alkaline-earth syenite	Trachyte
Alkaline K-syenite	K-trachyte
Alkaline Na-syenite	Na-trachyte
Quartz syenite-diorite	Trachydacite
Syenite-diorite	Trachyandesite
Gabbro-syenite (or monzonite)	Trachybasalt, trachydolerite
—	Albitized liparite, liparite-dacite, dacite, etc., up to basalt

[1] Rocks with about the same content of plagioclase and K-Na-feldspar, intermediate between granite and granodiorite.

[2] We assume conditionally that dacites are analogues of granodiorites, and andesite-dacites are analogues of quartz diorites. The term, "dacite", partly includes analogues of quartz-diorite (as well as of adamellite), while andesite-dacites are understood to be analogues of more "basic" quartz diorites, alone. However, we believe it more proper, in a rectified nomenclature, to keep dacite as analogous of granodiorite, by correspondingly narrowing down this term, because most dacites correspond in chemical composition, to granodiorite [3].

[3] Plagiogranite and tonalite make up a special branch of intrusive rocks and are introduced here conditionally, between granodiorite and quartz diorite.

plagiogranite would be "plagioliparite", with "plagiodacite" for tonalite analogues.

The inconsistency in this nomenclature, expressed in two terms (dolerite and basalt) for rocks with the same composition but differing in texture is quite justifiable. Indeed, a differentiation of these varieties, quite conspicuous, as a rule, in mapping, is important in determining the morphology of bodies formed by them. However, for better uniformity, the term, "dolerite", should perhaps be replaced by "dolerite basalt".

In a tabulation of extrusive rocks so organized and completed, a rock of any composition will have its definite place and name.

Structural criteria, quite important in extrusive rocks, should be made part of a name, as adjectives. One such criteria is the presence of inclusions. Varieties of liparite and dacite are best distinguished by inclusions of colored minerals and quartz. However, there are instances, as in the trachyte series, where the nature of the feldspars is an important criterion. To be sure, intermediate and basic extrusives are best characterized by the presence of colored minerals in their inclusions. When a rock is free of inclusions, an adjective, "aphyric", should be added to its name. A less important textural criterion, insofar as it is impossible to use it in field work is the groundmass texture. However, where this criterion becomes important for some reason, it should also be introduced into the name.

In this nomenclature of extrusive rocks, textural terms such as felsite, felsite porphyry, aphyrite (of the paleotype nomenclature) will not be substitutes for the name of a rock with a specific composition.

In speaking of the principles of naming rocks of the vein and dike facies, Ye. K. Ustiyev quite correctly states that names of extrusive rocks should be applied also to "subvolcanic and dike rocks with a porphyritic texture". He completely rejects such names as "diabase" and the corresponding "gabbro-diabase" for dike rocks, while deeming it possible to keep such names as quartz porphyry and porphyrite for the corresponding acid, intermediate, and basic intrusive rocks with porphyritic textures. This concession to common usage detracts from Ye. K. Ustiyev's principle of a single nomenclature for vein and dike rocks.

We believe it most expedient to call [porphyritic ?] intrusive rocks of any origin, which contain metastatic glass or the products of its subsequent decrystallization, as well as their extrusive analogues, porphyries. The same rocks but crystallized with a porphyritic texture should be called correspondingly, granite porphyry, granodiorite porphyry, diorite porphyry, gabbro porphyry, etc.

Diorite porphyry and gabbro porphyry are synonyms for diorite porphyrite and gabbro porphyrite. However, inasmuch as the part, "porphyry", like terms "porphyritic" or "uneven-grained", designates only the textural features of a rock while its composition is reflected in the part of the name preceding it, the term, "porphyrite", as a substitute for "porphyry" is superfluous. This idea, a logical conclusion from the preceding premises, is not original with us. Most foreign petrographers have long since abandoned the term, "porphyrite", in names of intrusive rocks with a porphyritic texture.

These considerations are not a mere simplification which goes with the abandonment of the genetic principle of classifying igneous rocks. Just as the standard nomenclature discriminates between vein quartz porphyries and extrusive quartz porphyries, so the proposed nomenclature should distinguish liparites from vein liparites.

Thus, we base our distinction between vein, dike, and endocontact facies on the principle that the name of an igneous rock should reflect its composition and degree of crystallization, rather than cooling-off conditions. The consolidation site, be it a fracture, a chamber, or the surface, should not be reflected in a rock name.

This will do away with the confusion in terms occurring when the origin of igneous rocks and the form of their geologic bodies cannot be ascertained. In addition, this principle is more consistent because any classification of extrusive rocks by occurrence is quite arbitrary. Suffice it to say that granites in batholiths, laccoliths, stocks, and dikes are always granites, while liparites in the feeding channels, feeding fractures, and those already at the surface, commonly bear different names.

We should like to state, in conclusion, that it is high time for reorganization and a radical improvement not only in the nomenclature but in the classification of all extrusive rocks.

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ON THE ARTICLE BY G. V. ANDREYEV, "CONTACT-INFILTRATION SKARNS NEAR CARBONATE BODIES OF THE KONDERSK MASSIF"[3,4]

by

V. I. Kitsul and M. A. Bogomolov

In our 1959 work on the Kondersk massif, we studied carbonate rocks and skarns in detail in all their outcrops and occurrences. The results of this work radically contradict G. V. Andreyev's concepts on the nature of these carbonate rocks and on the origin of the skarns, as set forth in his article.

G. V. Andreyev assumes that the Kondersk massif carbonate rocks are carbonatites. Now, there is no reliable data on the presence of carbonatites related to ultrabasic rocks of this type, in the absence of ultra-alkalic rocks.

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[3] O stat'ye G. V. Andreyeva "Kontaktovo-infil'tratsionnyye skarny vblizi karbonatitovykh tel kondërskogo massiva".

[4] Doklady, Akad. Nauk S. S. S. R., vol. 128, no. 4, 1959.

It is pertinent to inquire into the reasons for such an assumption. Our observations of the occurrence of the Kondersk carbonate rocks, as well as of their texture, and mineral composition, lead us to the conclusion that there are no such reasons.

The Kondersk massif is located on the eastern margin of the Aldan shield, in the Maya River basin. It is a cylindrical stock of ultrabasic rocks, six km in diameter, fringed by a broken-up ring of gabbro, diorite, and monzonite. The ultrabasic rocks are represented largely by dunite, gradually changing to peridotite, toward the periphery, and then to pyroxenes (kos'vite). The lateral Sinian rocks are disturbed in the vicinity of the massif, to form a dome-like structure reflected in the relief by an annular ridge. The ultrabasic rocks, being weaker, form a sink. Exposed on interior slopes of the annular ring, between the ultrabasic core and the uplifted Sinian rocks, is a ring of biotite-, amphibole-, and sillimanite gneisses and carbonate rocks.

These carbonate rocks rest exclusively on metamorphics enclosing the massif; their texture and composition suggest the presence of a single metamorphic facies, along with the gneisses. They have been nowhere observed in outcrops among the intrusive rocks, so that G. V. Andreyev's statement to the effect that they occur in veins and in intrusive rocks has no basis of fact. He makes this categorical conclusion merely on the basis of skarn fragments in the talus slopes of intrusive rocks.

G. V. Andreyev also speaks of carbonate rocks cutting the gneisses, while as a matter of fact, they are conformable everywhere, as clearly seen in outcrops.

The metamorphic section represented by gneisses, quartzites, and marbles, is everywhere characterized by its consistent metamorphism, an intensive migmatization, and a complex structure. All metamorphic rocks, including the carbonate, are complexly plicated and show linear structures. All these features of composition and texture of the metamorphic body suggest a regional metamorphism, unrelated to the massif.

Considering all these features, we assign this metamorphic section to the pre-Sinian rather than the Sinian, because the latter formations show no appreciable metamorphism in the vicinity of intrusive bodies of the Kondersk massif.

In mineral composition, the carbonate rocks are common marbles, brucite marbles, and forsterite-diopside calcifers, all free of rare-metal mineralization typical of carbonatites. On the other hand, we have found minerals such as ludwigite, never associated with carbonatites.

It follows from the above exposition that there is every reason to believe that the Kondersk carbonate rocks are indeed regionally metamorphosed, originally sedimentary pre-Sinian rocks.

By erroneously taking these carbonate rocks for carbonatites, G. V. Andreyev presents an utterly wrong mechanism of formation for the Kondersk skarns and an equally wrong analysis of the metasomatic zonation.

Present in the Kondersk skarns is a clean-cut superposition of calcareous skarns over magnesial, and a development of lower-temperature minerals on higher-temperature ones (phlogopite on spinel; epidote and sericite on plagioclase). However, the author lumps minerals of different facies and stages in the same metasomatic column (spinel and garnet; diopside and epidote). In so doing, he disregards a number of skarn minerals (plagioclase, brucite, forsterite, wollastonite, scapolite, phlogopite, clintonite) and even entire skarn zones (spinel-diopside, garnet-wollastonite, near-skarn rocks). It should be noted that we have not observed a carbonate-kos'vite contact, anywhere. It appears that the author mistook for kos'vite, an apogneissic near-skarn rock somewhat similar to it and consisting of pyroxene with a small addition of plagioclase.

For all these reasons, the author's conclusion that this metasomatic column (including minerals of different stages) has originated under isothermal and isochore conditions is theoretically incorrect. It leads the author to the erroneous idea, in the light of D. S. Korzhinskiy's theory of metasomatism, that Al_2O_3 is quite mobile, in this process.

A study of thin sections shows that the growth of metasomatic zones proceeds from aluminosilicate rocks to the carbonate. Consequently, perovskite-monticellite rocks are developed on calcifers, definitely following the banded texture of the latter. Many zones exhibit an alternation in the composition of pyroxenes and garnets, which suggests their bimetasomatic rather than infiltrational origin.

Thus, the actual data on skarns, too, contradict the author's concepts of their type and origin.

In the light of the above considerations, G. V. Andreyev's thesis on the nature of carbonate rocks and on the type and origin of the Kondersk skarns cannot be regarded as reliable and should be reconsidered in accordance with actual data.

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OBSERVATIONS ON THE ARTICLE BY N. S. SKRIPCHENKO, "ALTERATION IN DIKES CUTTING THE DIZILKOL, PYRITE DEPOSITS (NORTH CAUCASUS)"[5,6]

by

Yu. I. Dryzhak and R. L. Shustikov

In believing the North Caucasian pyrite deposits to be syngenetic with their enclosing volcanic rocks, N. S. Skripchenko puts much emphasis on the relationship between dikes and mineralization.

A close generic relationship between the extrusive and dike complexes is obvious in the Kizilkol, deposit. Under such conditions, the relative age of dikes and mineralization is of foremost importance for a correct interpretation of the origin of this deposit.

On the basis of his study of alteration in dikes "cutting" the ore body, N. S. Skripchenko strives to demonstrate a post-ore origin of this alteration and, as a corollary, a post-ore age of the dikes. However, his conclusions often contradict his observations and are not convincing.

In considering the relationship of dikes and mineralization, diabase dikes should be disregarded because there is no evidence of their cutting the pyrite bodies.

A study of the petrography and chemical composition of the "cutting" dikes gives every reason to assign them to diorite rather than to granodiorite porphyries.[7]

A comparison of the chemical and mineral compositions of unaltered (in the enclosing rocks) and altered (in the ore body) parts of the diorite porphyry dikes reveals a regular increase in the content of potassium and silica in altered segments, with a reduced content of iron, magnesium, and calcium. Mineralogically, this is reflected in the almost complete disappearance in these segments of albite, chlorite, and carbonate minerals; and in an abrupt increase in the importance of quartz and sericite. In addition, pseudomorphs of pyrite on magnetite have been observed often in composite thin sections, along with pyrite inclusions, a fact utterly ignored by N. S. Skripchenko. The presence of sulfides in altered dikes has also been corroborated by chemical analyses (see Table 2, p. 88) which have revealed the presence of pyritic sulfur. In most cases, the presence of pyrite in dikes within the ore body, often in considerable amounts, has been reliably determined with the microscope.

All these facts are an unquestionable proof that the alteration of dikes in diorite porphyries took place in an alkaline medium, at higher concentrations of hydrogen sulfide, i. e., under conditions quite similar to those of the mineralization.

A number of other facts which we have observed also indicate a pre-ore age for the dikes; e. g., dikes of diorite porphyries in the lateral rocks show even, rectilinear contacts; in the ore body, the contact between altered dikes and ore is quite uneven, with bends and numerous reentrants and vein-like encroachments of the ore into the dike. A partial replacement of altered dike rock by ore is quite possible, in the latter situation.

N. S. Skripchenko states on p. 89, "An examination of a large number of polished sections has not revealed any substantial difference between ores at the dike and away from it". This observation, a completely correct one, in no way proves the post-ore age of the dikes; if anything, the opposite is true. It is known (Stevenson, G. F. Chervyakovskiy, T. N. Shadlun) that dikes of basic and intermediate rocks, in intruding sulfide bodies of pyrite-chalcopyrite composition, bring about the appearance of high-temperature sulfides of low sulfur content. In pyrites, this would produce a thin "firing crust" consisting mostly of pyrrhotite. In subsequent metamorphism, the latter forms an aggregate of pyrite and magnetite. However, neither we nor the author have encountered any trace of pyrrhotite and magnetite, in the vicinity of the dikes.

In considering the physicochemical conditions of alteration in vein rocks, N. S. Skripchenko is in contradiction with some of his own conclusions (that chlorite is stable in an alkaline medium, p. 88), as well as with many facts. In believing that the dikes are altered as an effect of acid solutions formed in the passing of oxygen-rich waters (probably surface) through the pyrite deposit, the author utterly "forgets" that sericitization is possible only in an alkaline medium. In an acid medium clay minerals of a kaolinite type are formed instead of sericite, which is what we observe in those segments of the deposit where acid ore waters circulate through fractures in various rocks.

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[5] Zamechaniya k stat'ye N. S. Skripchenko "Ob izmeneniyakh dayek, sekushchikh kolchedannuyu zalezh' kizilkol'skogo mestorozhdeniya (severnyy kavkaz) .

[6] Izvestiya Akad. Nauk S. S. S. R., ser. geol., no. 6, 1960.

[7] In an article published in "Geologiya rudnykh otlozheniy" (No. 2, 1960) , N. S. Skripchenko also calls them diorite porphyries.

Such unconvincing and contradictory conclusions of the author on the relationship of pyrite and dike formations cast a doubt on his approach to the problem of the origin of this deposit.

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LETTER TO THE EDITORIAL BOARD[8]

by

V. F. Kozlov

An article by D. P. Serdyuchenko, "The Origin of Archean ores in South Yakutia", in which the author lapses into a vexatious distortion of my data demonstrating a metasedimentary origin of the Aldan iron-ore deposits was published in Izvestiya Academy of Sciences, U. S. S. R., Geological Series., no. 8, 1959.

We read on p. 40, "Referring to data from the Pionersk (borehole 57-P) and Sivaglinsk (boreholes 38-S and 40-S) deposits, geologists of the South Yakutian Expedition, V. A. Pervago, L. M. Minkin, and V. F. Kozlov also note the error of L. I. Shabynin's statements on the absence of granite intrusions in ores and ore-bearing rocks and emphasize that this intrusion took place in already existing bodies".

In my capacity of exploration party chief and the author of the approved report on the Pionersk deposit, I deem it necessary to make the following observations.

Borehole 57-P, drilled on the south flank of the deposit did encounter banded magnetic ores with diopside, scapolite, and epidote, and with many conformable "injections" of granitic material, mostly orthoclase. However, the bulk of the Pionersk ore is represented by diopside-scapolite-magnetite varieties of the most diverse textures, with the magnetite formed metasomatically in near-skarn diopside-scapolite rocks.

This later metasomatic origin of magnetite is demonstrated, with rare exceptions, by its structural position in ores where granite material is missing.

A thin ore body (6 m) in borehole 57 exhibits a conformable alteration of diopside, magnetite, scapolite, and granitic material, in bands; but no direct cutting of magnetite bands by the latter, or vice versa, has been observed. It was therefore impossible to establish the macroscopic structural relationship.

Thin sections from the magnetite-scapolite and granite contact exhibited some partial penetration of K-feldspar grains by scapolite (as if in the process of replacement), which suggests that the scapolite is younger than the granite injection, let alone the magnetites.

Thus we observe here, as in other iron-ore deposits of the Aldan, a textural inheritance by magnetite ores in granite injections, from the original rocks, in a skarn-ore replacement. The original rocks of the Pionersk deposits were gneisses and crystalline schists, more or less granitized and migmatized. In a post-magmatic stage, the gneisses were metasomatically altered to diopside-scapolite rocks, with a subsequent deposition of magnetite. Granite injections, being more "inert", almost escaped the skarn-ore replacement so that their texture was inherited by magnetite ores, creating a false impression of granitization. This was the interpretation proving the metasedimentary origin of ores, by V. A. Pervago to whom we sent, in 1957, the rock samples from borehole 57-P.

Our 1957 report makes no mention of a granitization of the Pionersk magnetite ores, and D. P. Serdyuchenko's reference to V. F. Kozlov is groundless. L. M. Minkin has never visited the Pionersk site. In the 1950-1957 general report of the South Yakutian Expedition he merely described the geologic structure of the Aldan province, without touching on the topic of the origin of its iron ores. Naturally, he could not have cited any examples of granites cutting the ore bodies, as D. P. Serdyuchenko would have it. Therefore any reference to him in this article is also not justified.

On the subject of structural control of mineralization in the Pionersk deposit, discussed by L. A. Shabynin and D. P. Serdyuchenko, I have this to say: There is clean-cut evidence of tectonic movements preceding, accompanying, and following the mineralization of this deposit. The error of L. I. Shabynin and D. P. Serdyuchenko is that Shabynin denies the presence of post-ore movements, while Serdyuchenko feels the same way about the two others.

The presence of breccia-like ore textures wherein magnetite in thin, variously oriented veinlets cuts the diopside-scapolite rock or cements its fragments is proof of previous and contemporaneous tectonic movements. In a pre-ore stage, (probably the granitization stage), calcifers in the hanging wall, with thin intercalations of gneiss, underwent plastic deformation and squeezing; as a result, the more

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[8] V redaktsiyu "Izvestiy Akademii Nauk SSSR, seriya geologicheskaya".

"rigid" gneiss beds were shattered to form breccia-like calcifers and gneiss fragments, altered during a post-magmatic stage to magnetite-free diopside-scapolite rocks. At subsequent stages, the ground mass of calcifers was recrystallized; all traces of their plastic deformation were obliterated, remaining only in the morphology and in the manner of occurrence. Unfortunately, D. P. Serdyuchenko and his coworkers have not noticed these facts.

On the other hand, present in the overlying calcifers near their contact with the ore body are typical tectonic breccias with fragments of the diopside-scapolite rock, garnet skarns, magnetite ore, and migmatites. These fragments are sharply angular, usually with a carbonate cement. The breccias do not form a well-defined zone; tectonic movements of that time were in the nature of shifts without appreciable displacement and did not affect the morphology of the ore bodies and the structure of the deposit.

L. I. Shabynin has not seen such breccias; since their age is obviously post-ore, they cannot be cited as evidence of either metasomatic or metasedimentary origin of these iron ores. In this respect, the argument between L. I. Shabynin and D. P. Serdyuchenko is groundless.

In his work, D. P. Serdyuchenko implies that L. I. Shabynin quite arbitrarily regards metasomatic phenomena as a decisive factor in the origin of iron ores, allegedly without any consideration given to the geologic conditions. On the contrary, advocates of a metasomatic origin of the Aldan ores cite voluminous field data gathered in the course of exploration and study of these deposits; these data convincingly demonstrate the truth of this theory.

On the other hand, D. P. Serdyuchenko's arguments for a metasedimentary origin of these iron ores are based mostly on general geologic considerations not supported by specific data. For example, D. P. Serdyuchenko's assertion that all iron ores are associated with the same stratigraphic unit, the Fedorovsk formation of the Archean Iengra series, is erroneous. The 1958-1959 work of the South Yakutian Expedition has firmly established the presence of skarn magnetite ore showings in the Upper Dzhegulinsk Archean series containing carbonate rocks (The Magantas group of magnetite and phlogopite showings in the Sunnagin Range). At least two productive horizons of carbonate rocks with magnetite ores have been definitely established in the Fedorovsk formation itself.

D. P. Serdyuchenko's article contains other controversial points omitted here for lack of space.

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CHRONICLE

THE TWENTY-FIRST SESSION OF THE INTERNATIONAL GEOLOGICAL CONGRESS[1]

by

D. V. Nalivkin

This Session was held in Copenhagen, August 16-25; it had been organized by the Scandinavian countries (Denmark, Iceland, Norway, Finland, and Sweden). Director of the Organization Committee was Arne Noe-Nygaard, Professor of Mineralogy at Copenhagen University; with Theodor Sorgenfrei, Representative of the Danish Geological Survey and Danish Geological Institute, as Secretary General. The Organizing Committee, with the participation of outstanding Scandinavian geologists (O. Holtedahl, N. H. Magnusson, W. Marmo, and others) had worked out the schedule and the field trips.

The program consisted of reports on 21 subjects, a special consideration of a number of problems in 15 commissions and subcommissions and in eight international associations; also 45 field trips in Sweden, Norway, Denmark, Iceland, and Finland.

The program included some very urgent stratigraphic problems of the Precambrian, ancient Paleozoic, Ordovician, and Silurian, as well as of the Cretaceous-Tertiary boundary, tectonics, absolute age of rocks, petrography, mineralogy, geochemistry, origin of rocks, petroleum geology, marine geology, etc.

Participating in the Twenty-First Session, better attended than preceding ones, were over 2,600 delegates and about 1,000 persons accompanying them; over 2,000 absentee members, and about 500 official delegates.

The Soviet Union was represented by 71 persons. Members of the official delegation were D. V. Nalivkin (Chief of Delegation), N. A. Belyayevskiy (Assistant Chief), A. P. Vinogradov, M. A. Kashkay, B. M. Kosov, M. V. Muratov, K. K. Orviku, N. P. Semenenko, and A. A. Trofimuk. Delegates of organizations and schools of higher learning were Sh. A. Azizbekov, M. M. Aliyev, L. V. Altukhov, A. A. Amiraslanov, A. T. Aslanyan, G. P. Barsanov, P. L. Bezrukov, V. V. Bezsmertnyy, V. I. Belov, V. V. Belousov, I. I. Bersenev, A. A. Bogdanov, I. D. Buachidze, K. A. Vlasov, O. A. Vorob'yeva, P. D. Gamkrelidze, V. I. Gerasimovskiy, Yu. N. Godin, I. I. Gorskiy, V. I. Gromov, N. A. Yeliseyev, N. P. Yermakov, Ye. Ye. Zakharov, D. L. Kal'ye, I. I. Katushenok, V. N. Kozorenko, D. S. Korzhinskiy, G. F. Krasheninnikov, K. O. Lange, G. A. Mavlyanov, I. G. Matak'yan, V. V. Menner, V. V. Mikalauskas, S. P. Mirkamalova, V. D. Nalivkin, L. V. Ovchinnikov, A. V. Peyve, A. A. Polkanov, V. S. Popov, L. V. Pustovalov, Ye. A. Radkevich, S. P. Rodionov, I. S. Rozhkov, Ye. M. Sergeyev, A. V. Sidorenko, V. I. Smirnov, V. S. Sobolev, G. A. Sokolov, N. G. Sudovnikov, B. V. Tkachenko, Yu. P. Travinov, A. I. Tugarinov, L. N. Formozova, I. Kh. Khamrabayev, F. V. Chukhrov, Ye. T. Shatalov, M. S. Shvetsov, V. V. Shinkarenko, Ye. D. Shlygin, V. S. Yablokov, A. F. Yakusheva, and A. L. Yanshin.

The National Committee of Soviet Geologists had published a number of collections of problems to be presented before the Session. Lithuanian geologists also had published a regional issue dealing with the problems of the Session. A collection of papers by Soviet geologists to be read before international unions and associations holding their meeting at the same time and place had also been published at the same time. A total of 24 collections were published, including over 450 papers and articles (totaling about 400 printed sheets), all accompanied by English summaries.

The General Assembly of the Twenty-First Session was opened on August 16, by Antonio Garcia Rojas (Mexico), President of the preceding Twentieth Session. A. Noe-Nygaard (Denmark) was elected President of the

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[1] XXI Sessiya Mezhdunarodnogo Geologicheskogo Kongressa.

Twenty-First Session and T. Sorgenfrei (Denmark) and I. A. Dons (Norway) Secretaries General. The Assembly also concurred with the move by A. G. Rojas to include in the Council Bureau, besides the President and Secretaries General, all Vice-Presidents, according to the Congress Constitution, are delegation chiefs from each country.

Following a brief introductory address by A. Noe-Nygaard, a welcome was read from the Government of Denmark to the Twenty-First Session of the International Geological Congress.

The work of the Session was carried out in the following sections:

1) consideration of academic and organizational problems in meetings of the Council and the Bureau of the Congress;

2) meetings of international scientific organizations;

3) discussion of papers in sections.

An important item was the large exposition of new geologic maps and books. Demonstrated during the sessions and on evenings were moving pictures on geologic subjects. Field trips and scientific excursions took place prior to the Session and partly during it.

A. Organizational Topics

Voted on in sessions of the Council and Bureau of the Congress as a suggestion by Dutch and Swiss geologists, supported by the British National Geological Congress, for establishing an International Geological Union. Its main task will be to promote the study of geologic problems, to facilitate international cooperation in the field of geology and allied disciplines, and to assist in the work of the International Geological Congress. The Council ruled that a working commission, presided over by A. Noe-Nygaard and including Secretary General T. Sorgenfrei, work out a constitution for this Union.

Deeming advisable a change in the voting procedure, the Council resolved to work out and adopt a new voting procedure for the Twenty-Second Session, to be held in India, in 1964, at the invitation of the Indian Government.

The Council took cognizance of the Czechoslovakian delegation's offer to hold the Twenty-Third Session in Prague, in 1968, with field trips organized in that country as well as in the Polish People's Republic, German Democratic Republic, and Romanian People's Republic.

The Council recommended that future sessions of the Congress put more emphasis on economic and applied geology; it deemed it necessary to reestablish symposia on mineral raw materials (metals).

On a move by V. V. Belousov, President of the International Geodetic and Geophysical Union, the Council resolved to set up a commission to communicate with that Union on problems of the upper mantle of the earth.

The Council recommended to award the Spenidiarov Prize to Icelandic geologist S. Torarinsson. This recommendation was solemnly affirmed by the closing session of the General Assembly.

B. Work of the Sessions

Scientific papers presented before this session of the Congress were one of the most important aspects of its work. Its 21 sections held over 80 meetings to discuss over 350 out of 387 papers published in the corresponding issues of Proceedings of the Congress.

The sections were organized in the following fields: geochemical cycles; geologic results of applied geophysics and geochemistry; determination of absolute age of pre-Quaternary formations; chronology and climate of the Quaternary; the Cretaceous-Tertiary boundary; pre-Quaternary micropaleontology; stratigraphy and correlation of the Ordovician and Silurian; late Precambrian and Cambrian stratigraphy; Precambrian correlations and stratigraphy; marine geology; regional and structural problems in petroleum geology; petrographic provinces and extrusive and metamorphic rocks; granite-gneiss problems; genetic problems of ores, and endogenetic ore deposits; mineralogy and origin of pegmatites; structure of the earth's crust and the deformation of rocks; Caledonian orogeny; applied geology; planetary geology; glaciology and glacial geology; regional geology and geomorphology; petrography and sedimentation; etc.

In this short summary, it is impossible to give even a brief résumé of all the papers read in sessions. At the same time, it is necessary to pause for the activity of the sessions and to note some of the most essential topics presented in a number of papers.

Problems discussed in the two geochemical sections attracted the attention of many students in diverse fields, which was only natural because these problems are common to geology, chemistry, and physics. Strictly speaking, only the paper by L. A. Borisenok and A. A. Saukov on the geochemical cycle of gallium fell within the intended framework of the geochemical cycles' section. Most of the other

papers were on geochemical exploration (A. Dreimanis, Canada; H. E. Hocks, and M. L. Salmon, United States; B. Berze, Yugoslavia; A. A. Saukov, U. S. S. R.; and many others).

Great interest was aroused by papers on the absolute age of geologic formations. J. L. Kulp (U. S.) reported on a new scale of geologic time, based to a considerable extent on the work of Soviet students; his paper stirred up considerable discussion. According to the author, the several divisions of the absolute scale have the following values (in millions of years): $Cm_1 - 600$; $O_1 - 490$; $S_1 - 430$; $D_1 - 400$; $C_1 - 350$; $P_1 - 270$; $T_1 - 220$; $J_1 - 180$; $Cr_1 - 135$; $Pc - 70$; $Ec - 55$; $Oc - 35$; $Mc - 23$; $Pl_c - 12$; and $Pl_s - 1$.[2]

Much attention was attracted by the published papers of Soviet investigators: G. D. Afanas'yev, T. K. Kozhina, and I. Ye. Starik, on determining the absolute age of standard samples of muscovite, biotite, and microcline, by the argon method; A. P. Vinogradov, et al, on the age of the crystalline basement of the Russian platform; A. A. Polkanov, and E. K. Gerling, on Precambrian geochronology of the Baltic shield; and N. P. Semenenko, et al, on absolute age of the Ukrainian shield. All these papers demonstrate the broad scope of the absolute-age study in our country; at the same time, they expose the inadequate work with the rubidium-strontium method.

A considerable number of papers in the section of Quaternary geochronology and climatology dealt with problems of Pleistocene and Holocene geology. Papers by V. P. Grichuk, V. N. Gromov, N. I. Krasinov, K. V. Nikiforova, Ye. V. Shantser (U. S. S. R.), and M. Machinskiy (France) discussed general problems of Quaternary glaciation and subdivisions of the Quaternary system. Attention was aroused by K. K. Orlik's (U. S. S. R.) paper on Quaternary geology of the Estonian S. S. R.

Most papers on the Cretaceous-Paleogene boundary did not go beyond regional stratigraphy of the western states of the U. S., Mexico, Austria, Denmark, Italy, the Pyrenees, Japan, Pakistan, Madagascar, Nigeria, Tunisia, and Lybia. General stratigraphy of the Cretaceous was considered only in papers by A. L. Yanshin (U. S. S. R.) and E. Voigt (West Germany). A. L. Yanshin has demonstrated that, according to data extant, there is no need

[2] The absolute geochronologic scale compiled from data of Soviet laboratories obtained on native material was considered and approved by the Ninth Session of the Commission on Absolute Age at the Section of Geologic and Geographic Sciences, Academy of Sciences, U.S.S.R., in June 1960. This scale, approved for 1960, has been published in this magazine, No. 10, 1960. Editorial Board.

to review the position of the upper boundary of the Cretaceous.

In the section on Ordovician and Silurian correlation, too, most papers treated the stratigraphy of individual countries: Korea, Great Britain, Sweden, Australia, the Estonian S. S. R., some areas of the U. S., etc. The most significant were papers by B. S. Sokolov et al on the stratigraphy, correlation, and paleogeography of the U. S. S. R., and by M. Kay (U. S.) on Ordovician correlations within the U. S. W. Jaanusson (Sweden) and W. Berry (U. S.) set forth in their papers two substantially different world-wide Ordovician correlations, by graptolite faunas.

The section of pre-Quaternary micropaleontology discussed the data on ostracods, foraminifera, conodonts, and calcareous algae, and their stratigraphic value. Of great interest was G. A. Ireland's (U. S.) paper on separation of foraminifera and other microfossils by dissolving their enclosing rocks with acids; a correlation of lower Paleozoic sequences of Norway and the U. S had been achieved in that way. Papers by R. A. Reyment (Sweden) and N. Grecoff (France) demonstrated the considerable achievements in correlating Mesozoic deposits by ostracods. However, there had been comparatively little progress in the stratigraphic application of radiolaria and algae. It should be noted that chemical processing of material, which allows an application of many micro-organic remains in stratigraphy and which is quite popular in the West, unfortunately is not being used in our country.

Papers on late Precambrian and Cambrian stratigraphy reveal the great interest in this problem, not only in those countries where such deposits have long since been known (U. S. S. R., Scandinavia, Central Europe, North Africa, and America) but also in West Africa (M. Zimmerman) and boreal regions (J. Covie, K. Birkenmayer). Achievements in the study of these deposits make it possible to tackle the problem of a world-wide correlation of late Precambrian and Cambrian deposits and to refine our concepts of ranks and boundaries of their subdivisions (N. S. Shatshiy, B. Howell, P. Jupe, etc.). N. S. Shatskiy, in his paper, presented reasons for designating the Riphean as an independent group and considered the general principles of late Precambrian stratigraphy.

Papers on Precambrian stratigraphy and correlation were closely related in their subject matter to those on absolute age.

Petrologic problems were prominent in the work of the sections, with 68 papers read on this subject. Three regional papers were presented. That on alkalic rocks of the U. S. U. S., by O. A. Vorob'yev, aroused great

interest. Quite interesting was material presented by A. Simonen on petrographic provinces of Finnish svekofenids, and by A. Eardley (U. S.) on extrusive rocks and tectonic provinces of the western states.

A few papers dealt with igneous activity and metamorphism. Of particular interest were the presentations by Soviet scientists: D. S. Korzhinskiy on acidity-alkalinity in magmatic processes; V. S. Sobolev, on the effect of high pressure in metamorphism; and N. P. Semenenko, on metamorphism of mobile zones. Yu. A. Kuznetsov presented a paper on igneous formations and their classification.

Unquestionably interesting was the paper by E. F. Osborn (U. S.) on the effect of a consistent oxygen pressure on fractional crystallization in a simplified basalt system, on the basis of experimental data of phase relationship. G. Drever (England) drew attention to the problem of liquation, by citing the excellent globular structures in a picrite intrusion of western Greenland as a natural proof of silicate immiscibility. R. N. Browser (New Zealand) demonstrated in an original way the origin of peculiar olivine nodules. Of note is the paper by E. Crank and R. Oya (Canada) on an experimental study of anatexis, by fusing (in high pressure bombs, in the presence of water) crystalline rocks. A profound analysis of petrologic processes and structural deformation in the development of migmatites was presented by Bertelson (Denmark). G. P. Devignes (France) raised the question of the dioritization-granitization-degranitization ratio.

Singled out for special attention among extrusive rocks were ultrabasic complexes and alkalic rocks with carbonatites.

Two very informative papers were given by Simpson (Union of South Africa): on the amazing Damaraland subvolcanic annular complex of Southeast Africa, and on a large anorthosite massif in south Angola. J. E. Noble (U. S.) voiced the possibility that intrusions of ultrabasic magma are caused by a fractional fusing on ultramafic material of the mantle. New and interesting data were cited on ultrabasic rocks of Norway (M. H. Beatty, England) and California (G. W. Chesterman, U. S.). T. P. Thayer (U. S.) drew attention to the characteristic differences between the Alpine-type peridotite-gabbro complexes and stratified massifs.

Papers on carbonatites in association with alkalic rocks were well attended. G. Agar (Morocco) presented very interesting data on carbonatites of the Tamazert alkalic massif (northern part of the High Atlas Range) and on its origin. Papers by P. de Betuc and A. Meyer (Belgium) discussed carbonatites of Luech and the Congo. Another interesting paper was by P. J. Willy and O. F. Tuttle (U. S.), corroborating the magmatic origin of carbonatites, on the basis of experimental data.

Mention should be made of a number of general papers on metamorphism. A lively discussion was stirred up by A. P. Subrahmanim's paper (India) on petrology of the charnokite group of rocks. Of interest were E. Niggli's (Switzerland) data on metamorphic zones in the Swiss Alps. D. S. Coomba (New Zealand) reported on mineral facies in rocks of the New Zealand geosyncline. K. Smulikovskiy (Poland) discussed the eclogite facies of regional metamorphism in the east Sudeten area. R. Marshall presented extremely interesting data on the amount and isotope composition of lead in eclogites of the Munchenberg gneiss massif.

The majority of papers were of unquestionable interest because of their material on significant petrographic formations, because of their comparative résumés of individual provinces and formations, and because of genetic hypotheses presented in them and supported by original material and occasionally by experimental data.

Most papers in the marine geology section covered more or less specific topics. Worthy of mention is V. Rugg's paper (Peru) on the submarine Nasca ridge, traceable for about 1,000 miles in the Pacific, northwest of Peru; papers by F. P. Shepard (U. S.) and A. C. Snelgrove (U. S.) on bottom structures off the U. S. coast and on bottom relief of the Great Lakes; and B. Hiesen (U. S.) on primary structures of deep-water sediments, accompanied by a profusion of submarine photographs. Of interest is evidence of a wide distribution of ripple marks and animal tracks on the ocean bottom. P. L. Bezrukov (U. S. S. R.) spoke on sedimentation in the northwestern Pacific.

In the petroleum geology section, Soviet geologists described the new and major oil and gas provinces in Western Siberia (A. A. Trofimuk and V. D. Nalivkin) and in Turkmenia (Yu. N. Godin). Their reports, based on new material, aroused great interest. J. Fantow (U. S.) demonstrated that oil fields in the northern oil province of the Rocky Mountains had been formed as a result of isolation of Eocene traps, caused by various factors (faults, lithologic screens, etc.). Of interest was a paper by R. M. Thompson on geology and oil and gas prospects of Alaska.

Presented in the section of regional paleogeography were interesting papers of Tasmania, Australia, Japan, the U. S., Canada, Poland, the Pyrenees, and regions of the U. S. S. R. Major paleogeographic generalizations were made by A. B. Ronov and V. Ye. Khain (U. S. S. R.) on Mesozoic formations of continents; by J. Bein (U. S.), on Paleozoic deposits; and by R. Maak (West Germany) on the Gondwana. T

audience was interested in the paper by A. P. Vinogradov et al on paleogeography of the Russian platform and its geosynclinal fringe.

Papers on tectonics were discussed in sections on the structure of the crust and Caledonian orogeny. Both general theoretical and regional problems were considered. Naturally, the greatest interest was shown in papers synthesizing voluminous field data for momentous theoretical generalizations.

Thus, there was the interesting paper by P. J. Willy and O. F. Tuttle (U. S.) on material floating within the crust, at depths of 20 to 30 km. A. V. Peyve (U. S. S. R.) presented an orderly system of concepts on phenomena of magmatism and on the importance of faults in the structure and history of the crust. The novelty of this paper was in its classification and identification of groups of deep faults related to tangential movements. The tenor of E. Kraus' (West Germany) paper was the relation of geosynclines to very deep-seated faults. An interesting attempt to classify the principal types of tectonic structures of the earth was presented by V. Ye. Khain (U. S. S. R.) who emphasized the connection of deep faults with the earth's rotation.

A lively discussion was held on the paper by V. V. Belousov who presented his view on the mechanism of formation of folded structures. While he connected them with vertical movements of the crust, his foreign opponents favored tangential movements and supported their views with familiar data on continental drift, large thrusts, etc. However, P. W. Van Bemmelen (Netherlands) had arrived at substantially the same conclusions as V. V. Belousov. He ascribes the thrusts and folds to gravity slipping of rock bodies, as the result of a vertical movement of tectonic structures.

The historical geologic method, the principal tool of the Soviet tectonic school, was presented in an interesting paper by M. V. Muratov on the structure and history of development of the Alpine geosynclinal province of Eastern Europe and Asia Minor.

The central topic of discussion in the ore-formation section was the origin of bedded lead-ore deposits in carbonate sequences. Advocates of a sedimentary origin of bedded deposits, who believe that the formation of such deposits is related to a mobilization of ore material dispersed in sediments, by waters and solutions, reported their findings on the basis of data from Australia (N. H. Fisher, the Mt. Ise deposit), India (M. Roy Chowdery et al, Permo-Carboniferous deposits in the Western Himalayas), the Congo (G. Michel and G. Scolari, Precambrian deposits of Mt. Pass), Europe (W. Marmo, a number of Swedish, Silesian, and other deposits), and other regions.

In papers of the other school of thought, the formation of a number of nonferrous metal ore deposits (such as copper deposits of East Germany; pyrite ores of Sweden and Norway; etc.) were explained by an addition of ore material from hydrotherms (fumarole waters, etc.) during the deposition of sediments.

Interesting papers were presented on the origin of uranium and thorium deposits. Outstanding among them was the paper by Nabuo Katayama (Japan) who pointed out that most of the producing uranium deposits are associated with continental sediments. He believes that they originated either by precipitation of uranium out of ground water or by infiltration. Uranium deposits associated with continental Pliocene sediments of Spain were discussed by M. Alia who associates their origin with evaporation of surface water flowing into depressions from the adjacent mountain ranges. C. Mihalich reported on infiltration deposits of Yugoslavia (Clocoti).

Interest was aroused by L. Nel's paper on genetic problems of auriferous conglomerates in South Africa; E. Noble's paper on the origin of uranium ores of the Colorado belt; W. Witenbogordt's on the age of uranium mineralization in quartzites of southern Sweden; and V. I. Smirnov's (U. S. S. R.) on types of hypogene zonation in hydrothermal ore deposits.

Problems of applied geology were presented in a few papers. S. Mac Hines cited some data on principal reserves of ground water in the U. S. and underscored the great value of ground water in the national economy as well as its future importance. B. Bowen et al presented geologic and hydrogeologic characteristics of sites and methods of underground storage of radioactive refuse from nuclear laboratories of the U. S. A. A. Amiraslanov's (U. S. S. R.) paper presented a résumé of the extensive experience in prospecting for stratified copper and lead-zinc ores. Kh. M. Abdullayev spoke on the alternation of metallogenic epochs in Soviet Central Asia. Attention was attracted by a 1:32,000 map of mineral raw material of France, presented by P. Laffite and P. Perminguet and reflecting the composition, size, and form of the deposits.

C. The Work of Commissions and Other International Geological Organizations

Associated with the International Geological Congress are some twenty commissions and committees, also associations and unions coordinating their work with that of the Congress. This session has demonstrated that the activity of many of these organizations was intensified in recent years.

<u>The Commission on the Geologic Map of the</u>

World is now represented by President F. Blondel (France), Secretary F. Rousot (France); Vice-Presidents: W. Johnston, for North America; A. R Lamego, for South America; A. Benz, for Europe; F. Dixi, for Africa; N. A. Belyayevskiy, for the Soviet Union; B. Roy, for Asia and the Far East; and Temple Bates, for Oceania and Australia. This commission held a very important meeting in 1958, in Paris, where delegates from 61 countries reviewed the basis for symbols and adopted a new legend for the geologic map of the world. Held at the same time were initial meetings of the subcommission on tectonic and metallogenic maps of the world, to outline the main trends of that work.

The Commission noted the progress in the making of composite maps. Organization had been completed for a new edition of composite geologic maps of the U. S., Brazil, Europe, three sheets of the second edition of the geologic map of Africa, the first geologic map of Asian and Far Eastern countries, as well as maps of Oceania and Australia. Major progress in geologic map making had been achieved in the Soviet Union.

These new maps constitute a substantial basis for a 1:10,000,000 Geologic Atlas of the world.

The Subcommission of the International Tectonic Map, at its initial meeting, paid its respect to the memory of its late President, Soviet Academician N. S. Shatskiy. It noted the outstanding contribution of N. S. Shatskiy to the creation of tectonic maps.

Academician D. V. Nalivkin (U. S. S. R.) was elected President of the Subcommission.

A. A. Bogdanov, Academic Secretary of the Subcommission, reported on the work of compiling a 1:2,500,000 tectonic map of Europe, participated in by almost all European countries. He presented a working draft of this map compiled under the direction of N. S. Shatskiy and A. A. Bogdanov. The Subcommission noted the great scientific merit of this map and recommended taking measures necessary for its prompt publication. It was decided to begin the work on the second edition of this map and to recommend cooperation with the International Geodetic and Geophysical Union in compiling an international seismotectonic map of Europe. It was also recommended to continue the work on an international glossary of tectonic terms and on principles of making tectonic maps of oceans. A discussion of these topics was slated for 1962, in Paris. A resolution was adopted on the preparation of a symposium on the tectonics of Europe.

N. N. Menshikov (France) reported on the status of work of compiling a tectonic map of Africa. There as a presentation of tectonic maps of the U. S. (G. Cohee), Australia (E. S. Hills), Czechoslovakia (W. Soubek and M. Maška), and Greenland (A. Bertelson). Also considered were a working draft of the tectonic map of Eurasia, prepared by Soviet scientists and presented by Academician A. L. Yanshin; a circumpolar map of the Arctic (by Yu. M. Pushcharovskiy) and a neotectonic map of the U. S. S. R. (compiled under the direction of N. I. Nikolayev and S. S. Schulz). V. V. Belousov spoke on the tectonics of the earth.

The tectonic maps and papers by Soviet scientists attracted much attention because of the novelty of their approach to tectonic problems and to the scope of the work. In connection with the neotectonic map of the U. S. S. R., the Subcommission moved to recommend a compilation of maps of recent neotectonics for all continents. The following coordinators were nominated: G. Cohee (U. S.) for North America A. R. Lamego (Brazil) for South America; D. B. Nalivkin (U. S. S. R.) for North Asia; Alexander (Malaya) for South Asia; E. S. Hills (Australia), for Australia; and the Association of African Geologists, for Africa.

The Subcommission on a Metallogenic Map of the World — W. Johnston (U. S.), President; Hydle (U. S.) and P. Routier (France), Secretaries; B. N. Yerofeyev, Vice-President for the U. S. S. R. since 1958, had been asked by the 1958 Paris Session to proceed with the compilation of mineral deposit maps and their correlation with geologic and tectonic maps. As early as 1958, Soviet delegates observed that such maps (of an index character) had long since been used by Soviet geologists. The main purpose of metallogenic maps is to show the genetic relationship of ore deposits to geologic structures. Such a metallogenic map of the U. S. S. R., for iron, was presented to the Subcommission by G. A. Sokolov (U. S. S. R.). Foreign metallogenic maps, exhibited in Copenhagen, fulfilled only one of the two conditions stipulated in Paris. They were only index maps of commercial minerals, drawn usually on a generalized topographic base. Such were, for instance, metallogenic maps of British Borneo, Northern Rhodesia, Portugal, individual countries of South Africa, etc.

General approbation was given to the working draft of a map of European coal measures, at a scale of 1:2,500,000, representing a valuable experiment in cooperation among scientists of various countries, under the direction of I. I. Gorskiy (U. S. S. R.). This map shows coal deposits of different ages and differentiated into hard and brown coals (lignite), with their respective stages of commercial development (actual production or its preparation; areas explored and ready for exploitation; prospective areas for exploration). Coal basins and deposits are classified in three groups, by their

reserves. Of interest also is the general geologic aspect of the map, with the distribution of coal measures shown in connection with definite structures in geosynclinal and platform provinces (folded provinces, foredeeps and intermontane troughs, syneclises, subsidences, etc.). It was resolved to prepare similar maps for other continents.

Amazing in their technique were metallogenic maps by the U. S. Geological Survey. They are drawn at a scale of 1:2,500,000, on transparent plastic sheets, for uranium, thorium, copper, lead and zinc, manganese, borates, asbestos, and a number of other minerals. These sheets are superimposed on a geologic map of the same scale. Japanese maps distinguish between the deposits by their products, age, and genetic (often morphologic) types. Some maps present modest attempts to indicate prospective areas for exploration.

The French maps of mineral deposits, with a very effective combination of symbols for morphology and origin, mineral and chemical composition of ores, and nature of the enclosing rocks turned out to be most interesting.

The Commission on the International Geologic map of Europe — A. Benz, President; Von Gertner, Academic Secretary, both from West Germany — has been preparing and publishing the sheets of a 1:1,500,000 Geologic Map of Europe. The first sheets were published in 1930; the final ones, embracing Baltic and Scandinavian areas, were considered at the Twenty-First Session. A new edition of the original sheets is planned.

The Commission on Stratigraphy reelected its Executive Bureau. L. Stormer (Norway) was elected President; I. I. Gorskiy (U. S. S. R.), First Vice-President; P. Pruvost (France), Second Vice-President; and G. Hennigsmoen (Norway), General Secretary. Members of the Bureau are Presidents of subcommissions: G. Roger (France), stratigraphic glossary; H. D. Hedberg (U. S.), stratigraphic terminology; W. P. Van Lequick (Belgium), Carboniferous stratigraphy; I. M. van der Vlerk (Holland), Quaternary stratigraphy; S. H. Houton (Union of South Africa), the Gondwana; also representatives of the committees: O Kuhn (Austria), stratigraphy of the Mediterranean Neogene; K. Gripp (West Germany), Neogene stratigraphy of the north; A. A. Tyadens (Holland), Upper Cretaceous (Maastrichtian) stratigraphy; G. K. Erben (West Germany), the Silurian-Devonian boundary, and stratigraphy of the Lower and Middle Devonian; and I. Fülep (Hungary), stratigraphy of the Mediterranean Mesozoic.

The Congress Council approved the following recommendations of the Commission:

1) To reflect in the Proceedings of the Congress the principles of stratigraphic classification and terminology as set forth in Circular 10 of the Subcommission on Stratigraphic Terminology;

2) To adhere to stratigraphic (chronostratigraphic) categories as defined at the Eighth Session of the International Geological Congress in Paris;

3) To approve the resolution of the Fourth International Congress of Carboniferous Stratigraphy (Heerlen), to the effect that the Carboniferous should be regarded as a single, discrete system, therefore not to be divided into the Pennsylvanian and Mississippian as proposed by North American stratigraphers.

The Carboniferous may be subdivided. The Tournaisian, Viséan, Namurian, and Westphalian, as defined by the Heerlen congress on stratigraphy, are to be the standard of correlation. Inasmuch as the boundaries of Carboniferous subdivisions are different in Western Europe and the Soviet Union, it is more convenient in Western Europe to use the geographic names for the Upper and Lower Carboniferous, the Silesian and Dinantian, respectively. The Pennsylvanian and Mississippian are not to be used as their synonyms.

The Commission confirmed the necessity for designating the Ordovician and Silurian as two independent systems.

The Association for the Study of Deep Zones of the Earth's Crust, presided over by P. Michault (Belgium), considered the schedule of the coming 1961 meeting with a field trip to areas of Freiberg (East Germany), Carl Var, and the Bohemian Massif (Czechoslovakia).

The Commission on Abstracting of Geologic Literature — H. M. Schurmer (Holland), President; C. van der Heide (Holland), Secretary; Members: A. Benz, West Germany; A. Butler, Great Britain; E. Wegman, Switzerland; Ye. Ye. Zakharov, U. S. S. R.; E. Ingerson, U. S.; Radzitsky d'Ostrovik, Belgium; G. Roger, France; A. Tyadens, Holland; and S. Houton, Union of South Africa — considered problems arising in connection with the organization of a new abstract periodical, in English.

The Commission reapproved the general idea of strengthening the national abstracting services.

The International Geochemical Union held a symposium on geochemistry of carbonate rocks. Many of the papers aroused consummate interest. B. Coubler (France) substantiated a direct proportional relationship, in carbonate sediments, between the content of strontium and magnesium, on one hand, and calcium, on the other. E. Ingerson (U. S.) spoke on some

general aspects of using the geochemical properties of minerals in determining the age of carbonate rocks and in paleotemperature studies.

The International Geochemical Union affirmed the ever-growing importance of isotope geology and the necessity for creating an international geochemical unit (commission or association), or an international geochemical congress, within the framework of the International Geophysical Union. The working-out of the status of such an international geophysical unit was entrusted to a group, with Academician A. P. Vinogradov as representative of the U. S. S. R.

The International Mineralogical Association approved a new constitution and elected D. J. Fisher (U. S.), President; K. I. Tilly (Great Britain), First Vice-President; G. P. Barsanov (U. S. S. R.), Second Vice-President; and H. L. Amoros (Spain), Secretary.

The Association held two symposia: 1) on the synthesis of minerals; and 2) on feldspars. The first symposium included many interesting papers. F. Boyd and England (Carnegie Laboratory, U. S.) reported on the results of their experiments on the synthesis of pyrope, at high pressures. S. Matches (West Germany) spoke on the synthesis of almandine, within the limits of stability for spessartite, and of garnets with pyrope and grossularite components, at high pressures. Hamilton and MacKenzie (U. S.) considered the synthesis of nepheline.

Presented at the symposium on feldspars were papers on the structure of feldspars; the composition of simultaneously crystallizing plagioclase and K-feldspar; the determination of the crystallization temperature for rocks containing feldspars; etc.

The vast majority of papers were based on extensive experimental material. A paper on some problems of the mineralogy of feldspars was presented by A. S. Marfunin (U. S. S. R.). The symposium supported the move by Berry, Parker, and Wenk, on compiling an index of feldspars, by the Fedorov method.

Also considered was the study of the natural origin of minerals, and a preliminary group was set up to organize a commission for this purpose. N. P. Yermakov is to represent the Soviet Union.

The next meeting of the Association is to be held in Washington, in 1962.

The International Hydrogeological Association heard the report and elected its guiding officers. O. K. Lange (U. S. S. R.) was elected Vice-President. Papers on hydrogeology were in the field of applied geology. The six papers by American geologists were on special topics of hydrogeology and engineering geology. Soviet hydrogeologists had prepared a special collection of articles for the meeting. However, these papers were not announced at the Congress because hydrogeology had not been included in its schedule.

The Carpatho-Balkan Association held a plenary meeting of its Council, presided over by N. P. Demenenko (U. S. S. R.). The Council considered the results of the past year's work and laid out the future program.

The International Commission on Clays elected Prof. I. Rosenquist (Norway), President and P. Graff-Peterson (Denmark), Secretary. The Commission heard papers on various problems in mineralogy, geology, and use of clays.

A special meeting took up the nomenclature and classification of clay minerals; after an animated discussion, the following definition of term "clay mineral" was recommended: "Crystalline clay minerals are phyllosilicates characterized by pseudo-hexagonally arranged silica-oxygen tetrahedons united with octahedral layers; they are usually represented by small particles and are capable of producing more or less plastic aggregates in the presence of water".

Considering the importance of a rational classification for clay minerals, the participants discussed a number of questions on the principles of such a classification. The majority was opposed to the introduction of new terms for natural mineral groups (candites, smectites, hormites) and agreed that it is more proper to name such groups by their principal clay minerals. Also rejected was the use of such terms as dimorphic (diform), trimorphic (triform), tetramorphic (tetraform). It was resolved that a swelling propensity should not be used as a group criterion in classifying clay minerals.

The next international conference on clays will be held in Prague, in 1961.

The International Association on Sedimentology was presided over by F. Shepard (U. S.). It considered papers on sedimentation conditions within the Mediterranean basin, on the coast of Florida, the Arctic basin, and elsewhere. Papers were read on structures of deep basins; the nature of flysch facies under (various) sedimentary conditions; the development of sedimentary processes on the arid coast of Chile, Peru, etc., within a present-day geosyncline. V. S. Yablokov presented an interesting paper on detailed paleogeography of the Donets basin, for the Carboniferous.

The next meeting of the Association is to be held in Belgium, in 1962.

The International Paleontological Union lected its officers: J. Paulson (Denmark), resident; G. Roger (France), General Sec-etary; and D. Leconte (Belgium), Treasurer. 'u. A. Orlov was elected representative of the oviet Union. The Union resolved not to in-ərrupt its activity between the sessions of the ıternational Geological Congress, as had been one before. It was resolved to continue the 'ork on the compilation of a world-wide roster f paleontologists, a file of collections, and ıe "Palaeontologia Universalia". A glossary f paleontological nomenclature is contemplat-d. The Union also contemplates organizing discussion of some momentous topics, such s ontogeny and environment of the inverte-rates; fossilization of mammals; the most ncient continental forms; fusilinids; paleoi-hthyology; etc. A plan of participation in the 'ork of the International Stratigraphic Com-ıission was drawn up (for Neogene strati-raphy of northern provinces — Ghent, 1961; leogene stratigraphy of Mediterranean pro-inces — Sadabel, 1961; stratigraphy of the ilurian and Devonian in France and Morocco; tc.).

The Union approved a recommendation for ational exchange centers for collections, in-ividual fossils, and casts.

Papers read before the Paleontological 'nion discussed phylogeny, paleoecology, re-ationship of major taxonomic units, etc., with ıuch attention given to algae. Of great in-ərest was a paper by O. Bandy (U. S.) on the elationship of foraminiferal structure and the nvironment; R. Ginsburg's (U. S.) paper on ıe mechanism of growth of algal "biscuits" in ıe tidal zone and below the sea level; D. Hill's Australia), on transitional forms between lcionaria and tabulata, tabulata and rugosa, ugosa and hexacorals. L. Torlo (England) nalyzed the facts supporting Harstang's theory f the origin of first vertebrates through an ıfantile alteration of tadpole-like larvae (of ıe present-day type unicata larvae), assuming ıat the vertebrates had originated from a umber of developing forms rather than from certain single genus. A total of 20 papers 'ere read by foreign scientists.

D. Geologic Books and Maps

A large exposition of geologic books and ıaps was held during the Session, with a total oor area of 2, 000 square meters. Over 40 ountries exhibited their new geologic publi-ations. Soviet geologists exhibited a :2, 500, 000 geologic map of the U. S. S. R. ; a umber of 1:5, 000, 000 maps (geologic, tec-onic, geomorphologic, Quaternary, hydro-hemical, etc.); maps from the first volume f the Atlas of Lithofacies Maps of the European . S. S. R. ; a Paleogeographic Atlas of the Ukrainian S. S. R. ; and a number of other maps demonstrating the variety of trends in geologic study of the U. S. S. R. and the scope of the generalizing effort.

Exhibits of other countries included interest-ing geologic maps; outstanding among them were sheets of a 1:500, 000 geologic map of Western Europe, 1:1, 000, 000 geologic maps of Norway and Sweden, and mineral deposits of France; 1:2, 000, 000 maps of mineral deposits of Mexico, Finland, and Sahara; and many others. There was an excellent draft of the map of one of the most inaccessible parts of Greenland. Highly commendable were large-scale geologic maps of various states of the U. S. ; a very interesting set of paleogeographic maps of the U. S., for the Jurassic, Permian, Carboniferous, Devonian, Silurian, Ordovician, and Cambrian, as well as a set of eight trans-parent globes with outlines of the present-day continents and the position of the poles, cli-matic zones, and seas in times past. French metallogenic maps were interesting in concept.

Attention was attracted by a very interesting tectonic map of Czechoslovakia, geologic and paleogeographic maps of Poland, and many others, compiled in East Germany and other people's democratic countries.

This exposition of geologic maps shows the great progress in geologic cartography in many countries of the world, in connection with the general expansion of geologic study.

Soviet geologic literature enjoyed great popu-larity. Curiously enough, a sign in the Ameri-can section asked the visitor: "Can you afford to be without geologic literature on a land com-prising one-sixth of the globe?" Under the sign there were copies of English translations of Izvestiya Academy of Sciences, U. S. S. R., Geologic Series; Doklady of the Academy of Sciences of the U. S. S. R. ; and reviews of the current Soviet geologic literature, all available by subscription. There were many French, German, and English translations of books by Soviet scientists.

Soviet geologic literature was represented by over 150 major titles in all the major branches of geology, beginning with 1956; in-cluding all geologic magazines and incidental publications. New geologic publications were exhibited by the Academies of Union Re-publics. Foreign geologists made many flat-tering observations on what they had seen. At the end of the session, the Soviet collection of books and maps was donated to Copenhagen University.

Also exhibited were more than 500 geo-logic books and maps published in the U. S., France, West Germany, England, and other countries, in the last 3 or 4 years. A

considerable number of new publications were exhibited by Czechoslovakia and Poland.

The Scandinavian countries exhibited a fine collection of literature on geologically and economically important areas. Of interest are the works on the geology and mineral resources of Greenland. Worthy of note are the substantial works by Finnish geologists on a detailed study of the Precambrian; also works on northern areas of Norway; and the works of Swedish geologists in petrology and ore deposits.

A shortcoming of the foreign literature is the disproportionately small number of geophysical titles. There was also a dearth of theoretical works on petrology, genetic problems of ores, and tectonics, as well as of paleontologic monographs. The new summaries on mineral resources are mostly based on previously published geologic material.

The exhibits of geologic equipment attracted much attention.

E. Field Trips

An important item in sessions of the International Geological Congress are field trips. At the Twenty-First Session, the field trips took place both before and after the meetings, in all Scandinavian countries (Denmark, Iceland, Norway, Sweden, Finland), for a study of their geologic structure and mineral deposits. Soviet delegates participated in 22 of the 45 trips. Of great interest were the visits to major ore deposits of Sweden and of non-ferrous and rare metal deposits in Norway. Many participants had a chance to become acquainted with Caledonian structures of Sweden and Norway and personally to inspect the large and flat thrusts in the northwestern margin of the East European platform, in the caledonia zone. Of importance was the trip to alkalic massifs in the Larvik area and elsewhere in Sweden and Norway; to pegmatites with the rarest minerals, carbonatites, nordmarkites, trondhjemites, and many others first described and named in the Scandinavian countries. Here occur outcrops described in classical works on the metamorphism of gneiss, on anatexis, palingenesis, and granitization. The observations of type localities of the Danian stage, along the Danish coast, were quite important.

The fact that leaders on these field trips were, as a rule, outstanding experts in Scandinavian geology greatly contributed to their success.

This Session of the Congress was one of the largest gatherings of geologists of all time, and extremely important for international cooperation and exchange in experience.

Papers presented before the Congress testify to the rapid progress of geologic knowledge and the increasing dependence on accurate analytic study and data of allied disciplines.

Modern stratigraphic studies are marked by striving for broad stratigraphic correlations a a general revision of old ideas on boundaries o systems, groups, and other stratigraphic subdivisions. Paleontology displays a tendency fo more profound study of phylogenetic relations among the groups of fossil organisms. The attention of many petrologists has been engaged the problems of origin of carbonates; the composition and evolution of basic alkalic and aclogit rocks, associated with which are showings of rare metal mineralization; and the formation o rocks with the highest degree of metamorphism Tectonists' effort have been concentrated on analysis of the mechanism and sequence of movements in the earth's crust. It is interesting to note that students of ore deposits have been engaged in numerous attempts to interpre bedded deposits of non-ferrous metals as cosedimentary, as well as in emphasizing the importance of infiltration processes in the formation of uranium ores in sedimentary sequences. In geochemistry, a new trend related to a more profound study of various aspects of the geolog process has been gaining in importance, along with the statistical and analytic studies.

The Soviet delegation is grateful to the Organizing Committee of the Twenty-First Sessic of the Congress, to Scandinavian geologists, a to all those collaborating for the success of thi session. We are also grateful to the Soviet Embassy in Denmark for its assistance while i Copenhagen.

FROM THE EDITORIAL BOARD

Published in No. 10, 1960, of this magazine was "The Geochronological Scale of Absolute Dating, from Data of the U. S. S. R. Laboratori for 1960".

We draw the readers' attention to the fact that divisions I-IV of the Cambrian in Table 2 are not subdivided in detail; for technical reasons, they are shown in the same column with the Paleozoic, Mesozoic, and Cenozoic. This however, as all geologists well know, does no mean an equivalence on the absolute scale, of such intervals as Precambrian IV and the Cenozoic, which were quite different in duration an undoubtedly in their share of geologic events.

Besides the laboratories mentioned in the test, much was contributed to the study of absolute age by the Laboratory of the Geologica Institute at the U. S. S. R. Academy of Science

ERRATA

Because of the author's oversight, in A. M. Barsuk's article No. 11, 1960, p. 98, line 13 from the bottom (English edition, p. 73, line from top, right hand column) reads, "has a viscosity of about 4.5 poises." It should rea instead, "has a viscosity of about $10^{4.5}$ poise